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THE CYCLOTRON OF THE BIOCHEMICAL RESEARCH FOUNDATION.

BY

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In the cyclotron constructed by the Biochemical Research Foundation many new features have been incorporated, a description of which may be of interest to those contemplating building a similar one. This cyclotron has been operating regularly up to 10 microamperes of deuterons at 10.2 million volts on an external target and 40 to 50 microamperes on an internal target placed between the dees. More recently, with an improved ion source, the cyclotron has been delivering a current of 30 microamperes of deuterons at 11 Mev. on an external target and there is little doubt that further increase in output can be attained. With this machine, it has been possible to produce radioactive material not only for indicator work but also for therapeutic purposes.

A general view of the cyclotron is shown in Fig. 1. The design of the magnetic circuit, vacuum chamber, the dees and the dee supports, ion source, high frequency system and auxiliary apparatus will be described briefly.

MAGNETIC CIRCUIT.

The magnetic circuit with the coil tanks in position is shown in Fig. 2. The various pieces were made of cast

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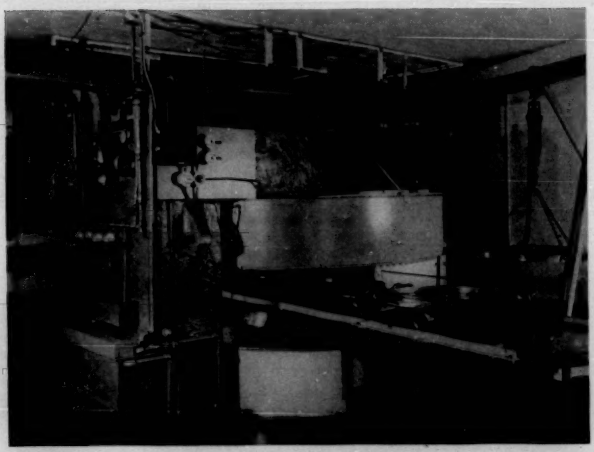
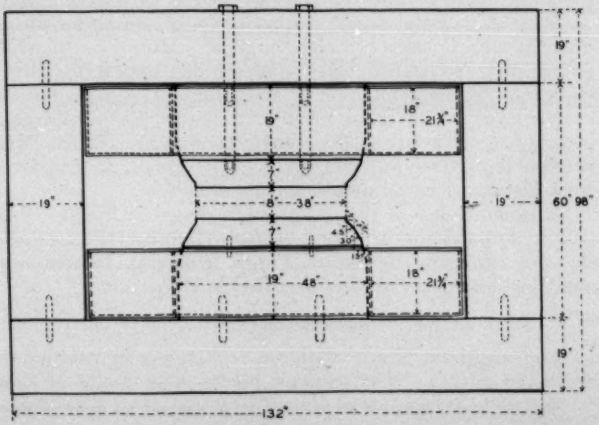
FIG. 1.



The Biochemical Research cyclotron.

FIG. 2.

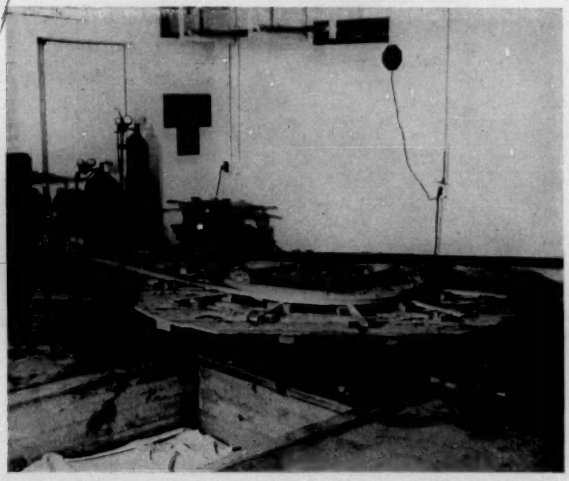


The magnetic circuit with the coil tanks in position. The frontal dimensions are as indicated. The width (not shown) is 48 inches.

Armco iron. The pole faces were constructed so that they could be replaced by others of either a different size or shape. We are indebted to Dr. Malcolm Henderson,[1] of Princeton University, for help in designing the pole pieces of the magnet.

The exciting coils were made from copper strip, 1 1/4" wide and 1/16" thick, wound with strips of heavy Kraft paper for insulation, to form layers of 225 turns each. They were

FIG. 3.



Winding the coils for the magnet on the turntable.

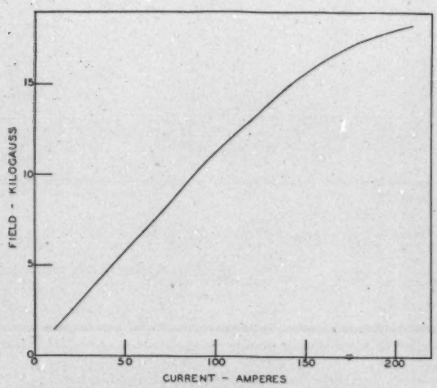
wound in the laboratory using the improvised turntable shown in Fig. 3. Each tank contains 8 layers separated from each other and from the sides and bottom of the tanks by strips of long leaf pine wood. Leads are brought out to a terminal board from the coils making various series-parallel connections possible according to the voltage requirements of the generator. To cool the coils, centrifugal pumps, one for each

[1] M. C. Henderson and M. G. White, *R. S. I.*, 9, 19 (1938).

tank, circulate oil around them and through two large automobile radiators immersed in running water which serve as heat exchangers. The water used here and in other parts of the cyclotron is pumped through a cooling tower and recirculated.

The variation of the magnetic field obtained with different currents is shown in Fig. 4. A field of 16 kilogauss is attained

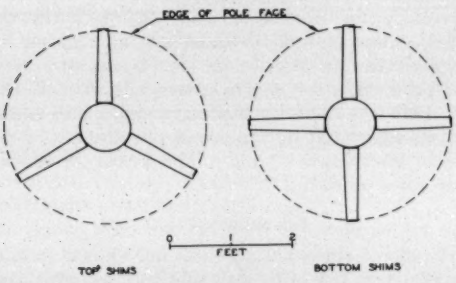
FIG. 4.



Variation of the magnetic field with the current.

with a power input of 155 amperes at 78 volts or about 12 kilowatts. A survey of the magnetic field was made in the following manner. A small coil driven at a distance by a synchronous motor was rotated between the poles of the magnet at various positions along 8 different radii. The current generated was commutated and read on a galvanometer using a biasing battery. The field was found to be symmetrical and showed no inhomogeneities in the iron. To produce a more intense beam it was necessary to insert "shims" of the nature shown in Fig. 5. This "shimming" arrangement proved to be the most successful of a number of arrangements tried, including the pyramiding of several discs of different radii, although it is not necessary to have the

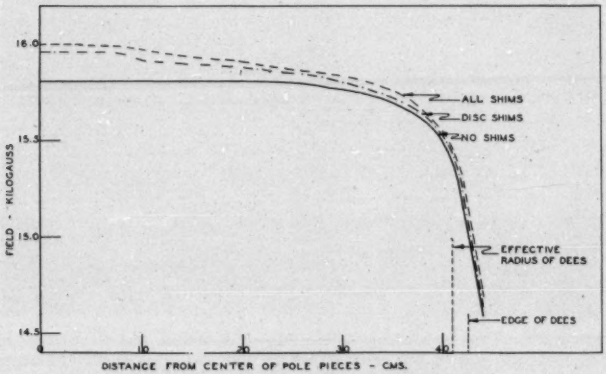
FIG. 5.



Arrangement of the "shims."

position of the rectangular shims around the disc exactly as indicated. The results of the survey, with and without "shimming," are shown in Fig. 6. The field of the magnet

FIG. 6.



Variation of the magnetic field with and without the "shims."

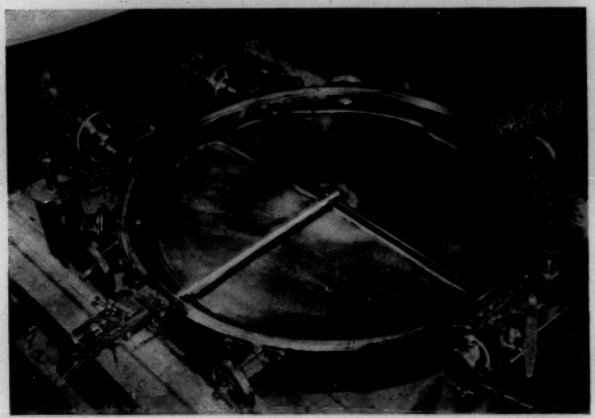
is kept constant to approximately 0.1 per cent. by a thermionic and photo cell regulator developed by the Biochemcial Research Foundation. This regulator is essentially that de-

scribed in a private communication to us by Dr. T. Perry of the University of Rochester and discussed in detail by Danforth.[2] Since circuit breakers are in the line from the generators to the magnet coils, it is essential to provide adequate protection for the magnet coils in case the line is opened. This was done by placing a spark gap consisting of 2 brass discs separated by a piece of paraffin paper across the terminals of the magnet coils. The paper breaks down at about 200 volts potential.

THE VACUUM TANK.

The details of the vacuum tank are shown in the photograph in Fig. 7. The side wall of the tank was made from

FIG. 7.



Photograph of the vacuum tank with the cover removed, showing the dees, the ion source, and auxiliary apparatus.

monel metal, 1″ thick, rolled to form a cylinder 37″ inner diameter and 4 1/2″ in height. A step 1/2″ wide and 1/2″ deep was cut in the inner side of the top and bottom of the

[2] W. E. Danforth, *R. S. I.*, 10, 211 (1939).

tank wall to accommodate Armco iron discs, 2″ thick, which form the top and bottom of the tank. The bottom disc was arc welded to the metal side and made vacuum tight with glyptal lacquer. The top was made vacuum tight by placing the cover on a rubber gasket in the step. With the iron discs and gasket in place the total height of the tank is 7 11/16″. The distance between the pole faces of the magnet is 8 1/16″, leaving only 3/16″ on the top and on the bottom for shimming, which is hardly adequate. The air gap within the tank, which accommodates the dees, is 3 11/16″.

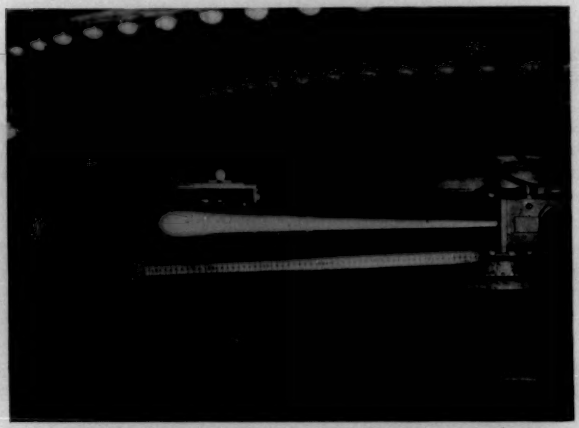
Various ports were cut through the wall of the tank to accommodate the necessary attachments. The beam is brought out from the tank through a window in a brass casting which is bolted to the side of the vacuum tank, and made vacuum tight with a rubber gasket. There is also a vacuum gate on the radiation chamber for introducing samples into the vacuum, thus making it possible to utilize the total energy of the beam. A beam of deuterons emerging from the radiation chamber is shown in Fig. 8. The current is approximately 4 microamperes and the energy as calculated from the absorption data [3] is 10.2 Mev. This value is in good agreement with that calculated from the constants of the machine. The beam has traversed a 0.001″ aluminum window and penetrated into the air for a distance of 62 cms. The current from a small radio frequency probe (3/8″ in diameter) extending through the tank wall is rectified and used as an indicator of the dee voltage. A tuned circuit may be inserted into the rectifier so that the voltmeter will respond to only one frequency.

The deflector is of the conventional type except that its support is insulated over its entire length with a quartz tube which effectively eliminates voltage breakdown to the grounded shield. It is 20 1/2″ long and 1 1/4″ wide and has a radius of 19 1/2″, which is an increase of 3″ over the effective radius of the dees. At the point where the beam leaves the dees, there is a 1/4″ space between the deflector and the defining edge of the dees, which increases to about 3/8″ at the other end of the deflector. The deflector is cooled with oil taken from the circulating system which cools the magnet

[3] M. S. Livingston and H. A. Bethe, *Rev. Mod. Phys.*, **9**, 261 (1937).

coils. A potential of about 45,000 volts is required to pull the beam free from the dees and tank when the radio frequency voltage is approximately 70,000 between dees. The potential is supplied by a transformer and full wave rectifier.

FIG. 8.



Photograph of the beam of deuterons emerging from the radiation chamber (10.2 Mev. energy and 4 microamperes).

THE DEES AND DEE SUPPORTS.

Details of the dees can be seen in Fig. 7. They are made of spun copper plates which fit together forming a sort of pill box, having a depth of 1″ at the periphery and of 2″ at the center. This was cut along a diameter into halves, soldered and reinforced with copper tubing which also provides means for the necessary water cooling.

The dee supports, schematic drawings of which are shown in Figs. 9*A* and 9*B*, are of more or less conventional design. The glass insulators are of the standard pyrex pipe type, but made of a special low loss glass (Corning 707 DG) and blown out as indicated. These insulators do not become heated and are exceedingly satisfactory. Pyrex insulators of similar

design have also been found to be satisfactory but some heating occurs. The copper shield with its end rounded is designed to prevent high field gradients in the insulators and to eliminate cathode ray beams which often destroy the insulators. Since the shield is connected to the tank, the radiofrequency current is carried by it rather than by the sylphon. All the parts are thoroughly water cooled as indicated and are easily removed for repair. The many rubber gaskets used have given no trouble.

The adjustment of the dees is accomplished by a special device shown in Fig. 9*B*. A stainless steel cylinder is threaded on both the outside and inside, the pitch on the outside being twice that on the inside. One end is made in the form of a hexagonal nut. A stub bolt having the same pitch as the inside of the cylinder is screwed to the stationary side of the support (brass plate *A*) and is made fast with a lock nut. The movable plate (brass plate *B*) is threaded to take the cylinder. When the cylinder is turned in a clockwise direction, it screws onto the stub bolt toward the stationary plate *A* but since the pitch on the outside of the cylinder is greater than that on the inside, plate *B* is moved away from plate *A*. The threads are made quite loose to prevent binding. This arrangement eliminates the use of springs, is sturdy and positive in action, and has proved to be convenient in the adjustment of the dees.

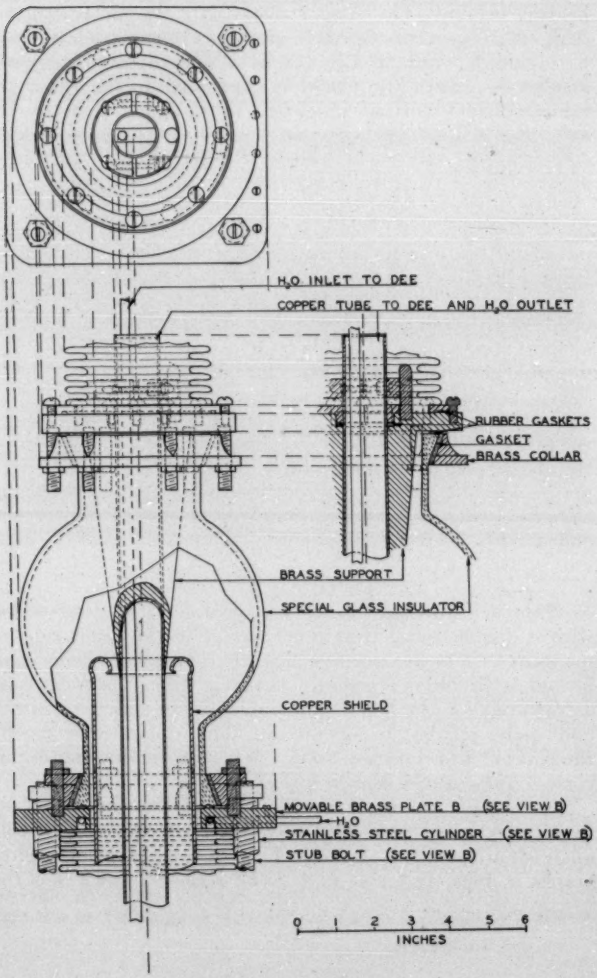
THE ION SOURCE.

The cyclotron was operated successfully for a long period with a double spiral tungsten filament in the usual type of ion source. For this purpose a 0.030″ tungsten wire was used, heated with direct current. Later a ribbon filament was substituted for the spiral and proved to be easier to install and more reliable in operation. The ribbon was 0.006″ thick, 0.11″ wide and 3/4″ long. A schematic drawing of this type of ion source is shown in Fig. 10.

An arc ion source, a modification of that described by Livingston, et al,[4] has also been used. A drawing of this modified arc source is shown in Figs. 11*A* and 11*B* and photographs in Figs. 12*A* and 12*B*. The filament, which is of the

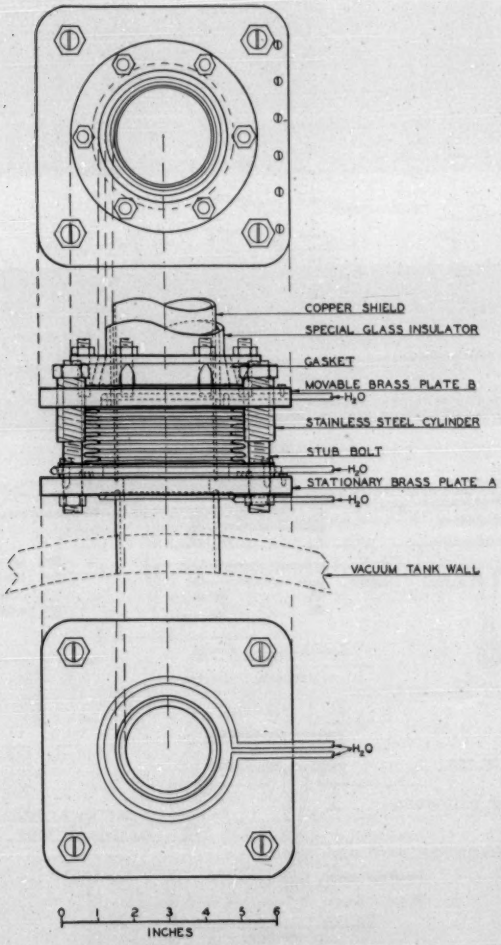
[4] M. S. Livingston, M. G. Holloway, and C. P. Baker, *R. S. I.*, 10, 63 (1939).

FIG. 94.



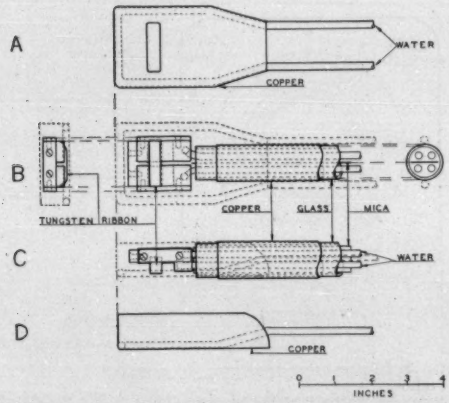
A. Schematic drawing of the dee supports.

FIG. 9*B*.



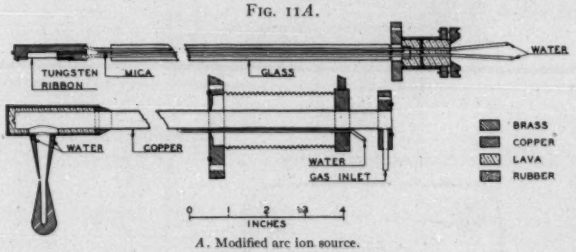
B. Schematic drawing of the device for the adjustment of the dees.

FIG. 10.



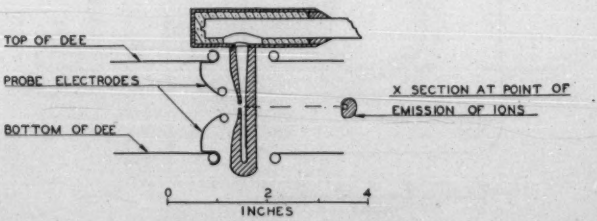
Standard type ion source with ribbon filament. *A*. Copper shield—bottom view. *B*. Ion source—bottom view with end views. *C*. Ion source—side view. *D*. Copper shield—side view.

FIG. 11*A*.



A. Modified arc ion source.

FIG. 11*B*.



B. Modified ion source with probe electrode.

FIG. 12A.

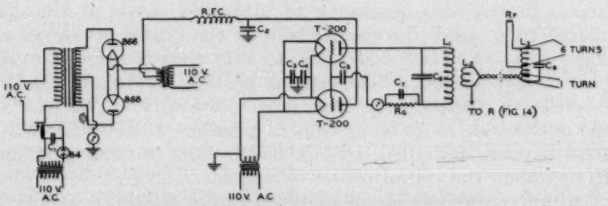
A. Photograph of the arc ion source.

FIG. 12B.

B. Photograph of another view of the arc ion source.

ribbon type just described, is heated with radiofrequency current of 60–100 amperes and about 200 kilocycles, supplied from a Hartley type oscillator, the details of which can be seen in Fig. 13. The filament power from the oscillator is

FIG. 13.

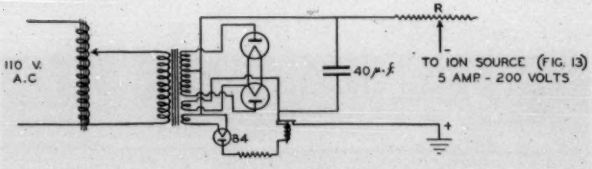


Oscillator circuit for heating the filament of the arc ion source.

C_1 = 4.0 μf. L_1 = 20 turns—$\frac{1}{4}$″ copper tubing 6″ I.D. × 10″ long.
C_2 = 0.0005 μf.
C_3 = 0.01 μf. L_2 = 5 turns—$\frac{1}{4}$″ copper tubing 7″ I.D. × 3″ long.
C_4 = 0.01 μf.
C_5 = 0.05 μf. L_3 = 9 turns—$\frac{1}{8}$″ copper tubing 6″ I.D. × 7″ long.
C_6 = 0.01 μf.
C_7 = 0.0005 μf. R_g = 1500 ohms—100 watts.
C_8 = 0.04 μf. R_f = ribbon filament.

transmitted for 30 feet by means of a non-resonant transmission line. Ordinary lamp cord is quite satisfactory for this purpose. A resonant transformer is then used to obtain the high current at low voltage necessary to heat the filament. About 1 kilowatt power is put into the plate supply of the oscillator. Current for the arc is supplied by a full wave mercury arc rectifier capable of supplying 5 amperes at 200 volts. See Fig. 14. The rectifier tubes for these circuits

FIG. 14.



Electrical circuit for the current supply for the arc for the ion source.

were made in the laboratory and are of the mercury vapor type with a special oxide coated filament.[5]

With this type of ion source inserted between the dees, a current is obtained of approximately the same magnitude as with the former ion source. Work now in progress indicates, however, that much greater currents can be attained. Two probe electrodes, as shown in Fig. 11*B*, were attached to the dees to increase the field gradient at the point of exit of the ions. It was also necessary to alter the shape of the discharge tube, since the copper wall at the center, as shown in Figs. 11*A*, 12*A*, and 12*B*, was so thin that it became overheated and melted. The central portion was made thicker in order to dissipate the heat more efficiently. The wall at the outlet hole must be as thin as possible, however, and the central portion shaped, to enable the ions to come out and to complete the initial orbit. With these changes a current of 30 microamperes on an external target has been attained. The arc current was approximately 0.5 ampere. The deuterium pressure in the tank itself was about one-half that re-

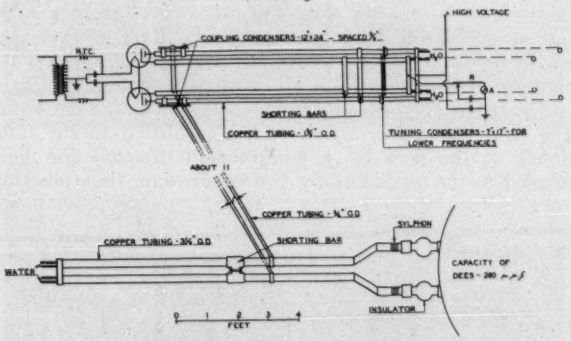
[5] *Rev. Sci. Inst.* (in press).

quired for the former type of ion source, which permits the use of higher voltages. The life of the ribbon filament is 8–10 hours, but experiments are now being carried out to prolong this time. It is probable that with further improvements in design and better adjustment, this type of ion source can be made to yield a current of 50 microamperes at 11 Mev. on an external target.

HIGH FREQUENCY SYSTEM.

The system for supplying high frequency voltage to the dees is shown schematically in Fig. 15. The oscillator tubes

FIG. 15.



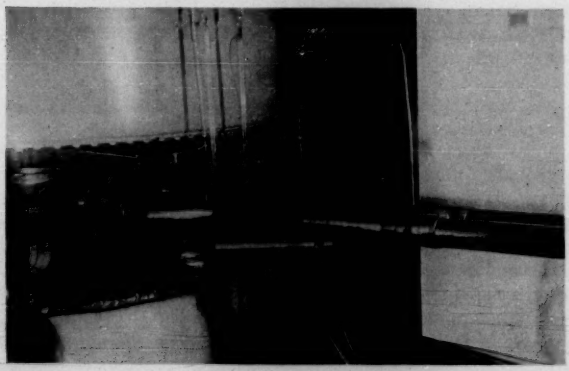
Electrical circuit for high frequency system for the cyclotron. R = 2500–3500 ohms. 1–1.5 amperes.

are of the Sloan type [6] and are pumped continuously. The anode has been enlarged to 4″ in diameter and the grid arranged to accommodate 4 hairpin filaments per tube. The filaments are made of 0.040″ tungsten wire each 22 1/2″ long, and are fastened at the bottom to the grid structure with tungsten springs and fused quartz insulating rings. A current of about 50 amperes at 26 1/2 volts is supplied to each filament. The filaments of the two tubes are in series and carry about

[6] D. H. Sloan, R. L. Thornton, and F. A. Jenkins, *R. S. I.*, 6, 75 (1935).

200 amperes at 53 volts. Power for the plates is supplied from a 4000 volt, 3 phase line, fed directly into step-up transformers. This is rectified with a 3 phase full wave rectifier system and is transmitted to the oscillators as indicated in the diagram at the terminal marked "High voltage." The current to the oscillators is regulated by means of water resistances in the ground side of the primary circuit. Normal operation requires 2.8 amperes at 10,000 volts or 28 kilowatts, although the rectifier system is capable of supplying 4 amperes at 11,000 volts. The rectifier tubes are of the mercury vapor type and were also constructed in the laboratory.[5] The filament and plate tank coils are tuned to a given frequency by adjusting the shorting cross bar. In case the bars are at the end of the quarter wave line, the wave-length can be further increased by adding capacity in the quarter wave line. A grid resistance of 2500 ohms, carrying a current of 1–1 1/2 amperes provides the grid bias. Water for cooling the plates and grids is supplied at the radiofrequency voltage node. The power from the oscillators is transmitted to the tank circuit of the dees by a non-resonant transmission line, coupled to the oscillators by two condensers, thus blocking

FIG. 16A.



A. Photograph of the dee tank circuit.

FIG. 16*B*.

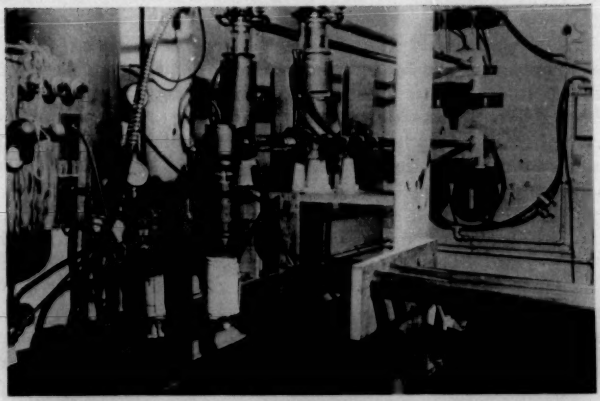
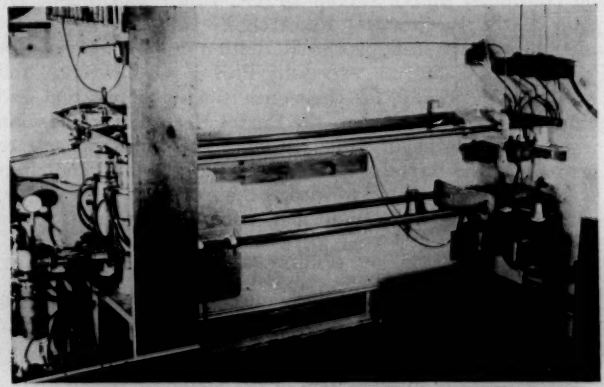


FIG. 16*C*.



B, C. Photographs of the grid and plate circuits, pumping system and oscillator tubes.

the D.C. potential from the dee tank circuit. The voltage distribution along the dee tank line is nearly linear with distance. At the far end of the dees, a voltage of 90 kv. is regularly attained. Tuning of the dee tank circuit is accomplished by sliding the shorting bar. The arrangement as shown in the figure is tuned for a wave-length of 26 meters. The sylphons provide a low loss flexible coupling to the vacuum tank which allows adjustment of the dees. The water inlet and outlet for cooling the dees as well as the dee tank coils is located at the voltage node which is at ground potential.

Details of the dee tank circuit are shown in the photograph of Fig. 16*A*. The pumping system, oscillator tubes, and grid and plate circuits are shown in Figs. 16*B* and 16*C*. It is of interest to note that the glass tube which insulates the grid from the plate of the oscillator is vacuum sealed with rubber gaskets and requires no sealing wax. We are indebted to Mr. John Evans of the Radio Corporation of America for help in designing this oscillator system.

The authors take pleasure in acknowledging the generous and continued support given by Dr. Ellice McDonald, Director of the Biochemical Research Foundation. They are indebted to the staff of the Radiation Laboratory of the University of California, especially Prof. E. O. Lawrence, and Dr. Donald Cooksey, for their enthusiastic coöperation and help. They are grateful to the Bartol Research Foundation for providing space in which to erect the cyclotron and to members of the Bartol staff for their many helpful contributions. They wish to acknowledge the excellent work of Mr. Frank Penny, the instrument maker for the cyclotron.

SUMMARY.

Certain features of the Biochemical Research Foundation cyclotron, which may be of interest to those building a similar machine, are as follows:

1. The design and construction of the magnetic circuit.
2. Results of a survey of the magnetic field with and without "shimming."

3. The construction and dimensions of the vacuum tank and deflector.
4. The design of dee supports with a convenient arrangement for the adjustment of the dees.
5. Modified ion sources using tungsten ribbon filaments, one of which enables the cyclotron to deliver a current of at least 30 microamperes of deuterons at 11 Mev. on an external target.
6. A high frequency system for supplying voltage to the dees.

"Hot" Lightning Used in Transformer Tests.—(*Power Plant Engineering*, Vol. XLIII, No. 8.) The first public demonstration of man-made "hot" lightning was made by Westinghouse engineers at Sharon, Pa., recently, simultaneous with the inauguration of an artificial lightning test for all distribution transformers of the completely self-protected class. The improved lightning generator was able to create artificial lightning complete with the relatively low current, long lasting "tail" that gives lightning its destructive burning effects. The engineers let loose bolts of "hot" lightning that set fire to a haystack, fused a pile of sand that instantly ignited cloth, and caused an electric power pole to burst into flame. Strokes from the previous form of lightning generators, by comparison, widely scattered the hay and sand, split the pole, and pierced the fabric without setting any of them ablaze. Lightning is not just the discharge of extremely high voltage—of the order of several million volts. Natural lightning has, in effect, three components; high voltage, followed by an extremely high current for a few dozen millionths of a second, and finished with a discharge of much smaller current lasting for a much longer period of time—up to a full second. The earliest lightning generators were simply high voltage generators, producing high potential, low current, lasting for only a few microseconds. Valuable as was this laboratory development it was not a very close approach to lightning since the current associated with it is too small to develop the full effects and damage on apparatus that results from combined voltage and current. The principal problem in the design and construction of a high-voltage high current lightning generator lay not in building a high-voltage element or a high current element but in hitching the two together. Some means must be had for releasing the current discharge two to ten millionths of a second after the voltage discharge is initiated. The answer was found in an ingenious but simple device known as a microsecond switch. It is an arrangement where heat from broken down air vaporizes a small quantity of fiber which is expelled violently across a gap obstructing the charge of the high current generator, lowering the gap's resistance and allowing it to dump its charge into the lightning circuit.

R. H. O.

THE PURDUE CYCLOTRON.

BY

W. J. HENDERSON, L. D. P. KING, J. R. RISSER, H. J. YEARIAN, AND J. D. HOWE,

Physics Department, Purdue University, Lafayette, Indiana.

In 1935 plans were begun by the Physics Department of Purdue University to build a cyclotron. The primary objective was to construct a compact instrument at the lowest possible cost. For this reasons standard materials have been used and much of the equipment has been built in the departmental shop. As a result the Purdue cyclotron presents a number of features differing from others of the same size.

The construction was begun by Dr. H. J. Yearian and J. D. Howe, who erected the magnet and constructed the water cooling system, and with the help of Mr. R. Jensen, the oscillator. The first three authors of this paper have been responsible for the completion of the project. The cyclotron has been in operation for eight months for the investigation of artificial radioactivities and has operated consistently for that time.

The magnet is of low carbon 1020 open hearth steel supplied by the Carnegie-Illinois Steel Company. The slabs from which the yoke is formed were hot rolled and the pole pieces were supplied as forgings. The poles, which taper from 40 inches at the yoke to 37 1/2 inches at the tip, have been shaped according to a formula derived by Bethe for securing as high a value of $H\rho$ as possible. The calculation is made to give minimum fringing flux, but does not take into account the requirements of the magnetic field for focusing and shimming. The tapered poles have the shape given by the equation:

$$r^2(y) = R^2\left(1 + \frac{4d}{\pi r}\log\frac{y}{d}\right) \Big/ \left(1 + \frac{4d}{\pi r}\log\frac{a}{d}\right),$$

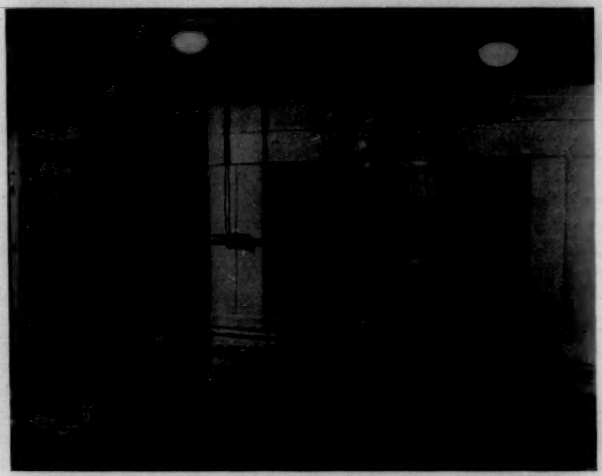
where $r(y)$ is the radius of the pole piece at a point y above the

equatorial plane of the air gap, R is the radius of the pole piece at a distance a from the equatorial plane, $2d$ is the width of the gap, and a is the distance between the yoke and the equatorial plane of the air gap. In a straight cylinder the value of $H\rho$ in the gap is

$$\frac{H_0 R}{1 + \frac{4}{\pi d} \log \frac{a}{d}} = \frac{H_0 R}{b}$$

where H_0 is the field in the pole piece at a point farthest from

FIG. 1.



Photograph showing the arrangement of magnet, oscillator and control panels.

the gap, while in the above tapered cylinder it is $H_0 R/b^{1/2}$. The pole pieces were machined in the Monon Locomotive Shops in a series of tapers so as to conform very closely with the above curve. The yoke of the magnet is 114 inches long, 83 inches high with cross sectional area of 8200 square inches.

The magnetizing coils for the magnet were wound in the

laboratory by Mr. J. D. Howe and assistants. The conductor is 7/16″ O.D. copper tubing of wall thickness .086″. Each coil consists of 13 pancakes of 2 layers each with 45 turns per pancake or 585 turns per coil. As the winding proceeded the tubing was wound with linen tape and coated with insulating varnish. The completed coil was wrapped with white duck

FIG. 2.

Photograph from the rear of the magnet; A, the quarter wave line, B, the heat exchanger, C, the pumping system.

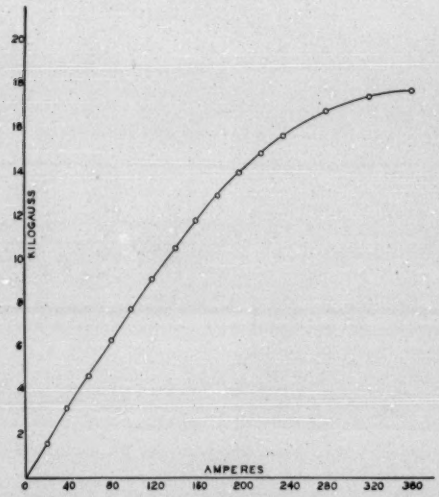
canvas and painted with water proofing varnish. The cross section of a completed coil is one foot square, which allows easy access to the cyclotron chamber when it is in place between the poles. The effects of fringing flux and the necessary precautions in mounting coils of this type have been described by Walerstein and Howe.[1] The completed magnet may be seen in Fig. 1.

The cooling of the windings is accomplished by circulating cold distilled water through the copper tubing, the pancakes

[1] Walerstein and Howe, *Rev. Sci. Inst.*, 9, 53 (1938).

being connected in parallel for the water circuit. The heat is dissipated to the water mains through a heat exchanger at *B*, Fig. 2, constructed in the shop. It consists of 125 copper tubes 8.5 feet long, 0.227 inch O.D. with a wall thickness of 0.02 inch soldered between headers in a 4 inch I.D. brass jacket. The distilled water is circulated through the tubes and the cooling water from the mains through the jacket. Typical operating conditions for 20 K.W. dissipation are:

FIG. 3.



The magnetization curve of the cyclotron magnet. The air gap is 4¼ inches. Ampere turns = 585 × amperes.

7.75 gal./min. distilled water at 20 lbs./sq. inch are cooled from 31° C. to 21.5° C.; 15 gal./min. cooling water at 15 lbs./sq. inch are heated from 13.4° C. to 18.5° C. The unit has ample capacity to cool the oscillator tubes in addition to the magnet.

The magnetization curve of the magnet is drawn in Fig. 3 The power is supplied to the magnet from a 110 volt D.C.

generator driven by a synchronous motor. The field of this generator is supplied from a small generator driven by a V-belt from the same synchronous motor. This arrangement gives a fairly constant voltage, and without further stabilization the magnetic field can be kept in tune by the occasional adjustment of a hand rheostat. An automatic stabilizer of the type developed by Perry [2] is being built but to date has not been connected to the magnet.

THE OSCILLATOR.

The radio frequency power is supplied by an oscillator of the tuned grid tuned plate type. The dee circuit consists of a quarter wave line directly coupled to an untuned transmission line with inductive coupling to the plate tank coil of the oscillator. The oscillator tubes are the commercial type (Federal Telegraph 332-C) rated at 25 K.W. plate dissipation. The use of neutralizing condensers permits effective adjustment of the grid excitation. The power supply is provided by a three phase full wave rectifier with mercury vapor tubes, United Electronics 972-A. We have found that a heavy duty choke, wound on the core of an old power transformer, placed in the lead from the rectifier to the oscillator helps in prolonging the life of the rectifier tubes by cutting down the heavy current drain when flashovers occur in the chamber.

The quarter wave line at *A*, Fig. 2, is made from a copper eave trough downspout of 3″ diameter. The inner ends are flared out to a diameter of 6″ where they are clamped to the outer ends of the dee supports. Water cooling tubes are soldered longitudinally along the outside of the pipe. The water for cooling the dees and the dee supports comes in the outer ends of the line and passes in rubber tubes down the inside of the pipe.

At present the frequency of the oscillator is 10.9 megacycles. The total power supplied to the oscillator is 25.5 K.W. (3 amperes at 8500 volts). Of this about 7 K.W. is dissipated in the dee circuit according to measurements of the temperature rise of the dee cooling water. Under these conditions measurements of the type suggested by Danforth and

[2] Perry, *Phys. Rev.*, 53, 943 (1939).

Sampson [3] indicate that the peak voltage between the dees is approximately 50 K.V. To date we have been held back by considerations of the oscillator tube life from increasing the power beyond this amount. When tuning the oscillator and adjusting the coupling between the transmission line and the dee circuit, it is convenient to have a relative indicator of the dee voltage. The dee voltmeters that we have used consist of a simple diode rectifier connected to a small insulated disc placed in the chamber wall so that it can "see" the dee. The details of the arrangement have been described by Whitmer.[4]

The oscillator and transmission line may be seen in the left background of Fig. 1. The control panels at the extreme left have been used in the work with α-particles. They are being duplicated at a distance of 50 feet from the cyclotron behind water shielding tanks.

THE CYCLOTRON CHAMBER

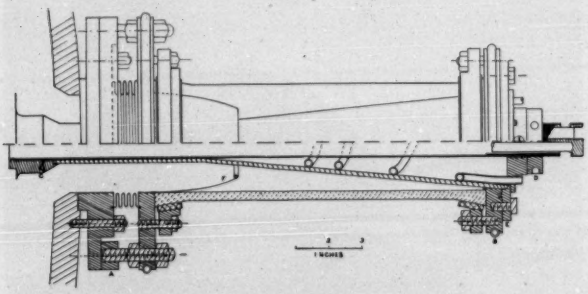
Many of the features of the Berkeley design have been adopted in constructing the chamber. It consists of an Everdur brass ring 7/8" thick and 38" O.D. The floor and lid of the chamber are steel plates 1 1/4" thick. The bottom is bolted and soft soldered in place. The lid was at first sealed with a rubber gasket of the V and groove type. Due to a slight warping of the plate after several months operation this gasket has failed and the seal is now made with plasticine.

The supports for the radio frequency electrodes are bolted directly to the chamber wall, the vacuum seal being made with a lead gasket between the flat brass plate and a flattened portion of the chamber wall. The insulators are the standard straight pyrex pipes 10" long and 3" I.D. The motion of the supports and hence of the dees in any direction is accomplished by the concentric ring arrangement as shown in Fig. 4, at *A*. To obtain good mechanical support for the electrodes a spun copper cone tapering to a cylinder 1" I.D. extends from the brass plates *B* at the outer end of the insulator in beyond the chamber wall. This cone is not evacuated, the vacuum seal being made with a rubber gasket *C* at the point where the inner end butts against the electrode. This rubber gasket

[3] Danforth and Sampson, *Rev. Sci. Inst.*, 9, 175 (1938).
[4] Whitmer, *Rev. Sci. Inst.*, 10, 165 (1939).

is compressed by tightening a nut *D* threaded on the outer end of the brass tube on which the electrode is mounted. Since good electrical contact is essential at this seal, the thickness of the gasket, *C*, is chosen so that when vacuum tight the two machined metal surfaces are in contact. The copper cone is threaded and soldered at the outer end to the plate, *E*, which is attached with studs to plate *B*. The gasket seal here again is such that there is a good metallic contact between the two plates. Besides the extra rigidity, this cone-shaped support eliminates the outer corona shield and also gives a low resistance path for the radio frequency currents to the electrodes.

FIG. 4.



The dee support.

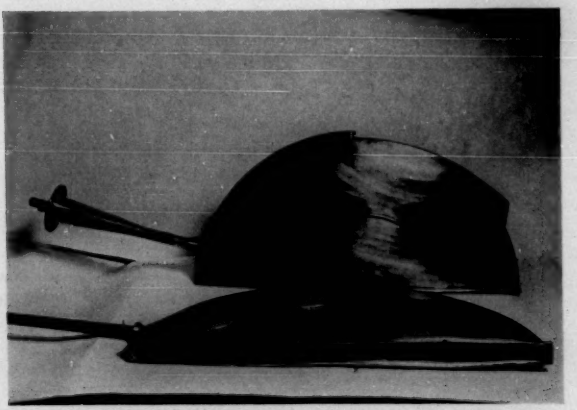
The inner shield has been reduced to a short spun copper cone, *F*, ending in a ring of 1/4″ copper tubing. Cooling coils are soldered into the cones. It has also been found necessary to water cool the sylphons by winding them with lead tubing. The glass supports are water cooled in the region where maximum heating occurs by a coil of thin walled rubber tubing wound on the glass.

The dees themselves are constructed by soldering copper sheet to a skeleton of copper tubing which supplies the water cooling. This is the construction described by Henderson and White.[5] At the time the electrodes were being designed,

[5] M. C. Henderson and White, *Rev. Sci. Inst.*, 9, 19 (1938).

the paper of Rose [6] appeared. His calculations of the ion paths for high energy ions in the cyclotron showed that the focusing, produced by the combination of the electric and magnetic fields, is such that the current realized depends on the height of the dees about one-half way out from the center. With a flat dee and the magnetic field necessary for accelerating high energy ions, only those ions produced in a region of from 15 to 30 per cent. of the dee height can be accelerated out to the periphery of the electrodes and for a given electro-

FIG. 5.



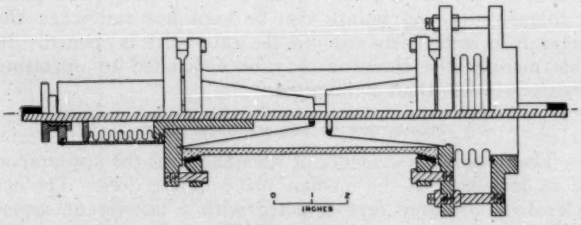
Photograph of the dees showing the conical support and inner gasket seal.

static capacity it is possible to obtain larger ion currents by shaping the dees to accommodate the ion beam. With this in mind the dees have been made in the shape shown in Fig. 5. The inside height at the center is 1 1/4", at the half-way point is 1 3/4" and at the edge 1". The merits of this shape could be decided by measuring the distribution with height of the circulating ion current in the widest parts of the electrodes. We expect to make these measurements at an early date.

[6] Rose, *Phys. Rev.*, **53**. 392 (1938).

The deflector support is attached to the chamber wall in the same manner as the dee supports. The insulator is an 8″ long pyrex pipe 2″ I.D. The copper corona shields are shaped as shown in Fig. 6. They are similar to those used by Haworth and King,[7] in high voltage accelerating tubes. There has never been any sparkover or bombardment of the glass up to voltages of 70 K.V. In normal operation the deflector voltage is about 50 K.V. The necessary adjustments of the deflecting plate are obtained by the two sylphons whose functions are obvious.

FIG. 6.



The deflector support.

We have not bypassed the deflector to ground through a condenser, but have placed a radio frequency choke between the deflecting plate and the rectifier. This gives the deflecting plate a radio frequency potential with respect to ground, and decreases the radio frequency component of the deflecting voltage. Opposed to this disadvantage is the fact that it allows the r.f. voltage on the dees to be balanced, and reduces the heating in the deflector support so that no cooling is necessary.

The voltage is supplied to the deflector from a voltage doubling rectifier using G. E. KC4 kenotrons. After the ion beam passes through the deflecting system it goes through a large brass stopcock with an opening corresponding to the shape of the beam. This stopcock serves to isolate the bombarding chamber from the main vacuum system and allows targets to be changed quickly and bombarded in vacuo.

[7] Haworth, King, Zahn, Heydenburg, *Rev. Sci. Inst.*, **8**, 486 (1937).

The pumping system, at *C* Fig. 2, of 3 oil diffusion pumps and a hypervac is mounted on a movable carriage. This is convenient for testing the chamber for leaks before it is placed between the poles. It also allows rotation of the chamber and pumping system as a unit so that the beam may be brought away from the magnet at any desired angle. The 4 inch diameter water cooled pumping line is fitted with a rubber seated gate valve. The gate valve and oil diffusion pumps are bypassed to the hypervac with a 1 inch diameter pumping line which is used for reducing the chamber pressure to that necessary for the diffusion pumps to operate. When it is necessary to open the chamber, as for example to replace a filament, the oil pumps can be kept hot and when the pressure is sufficiently reduced the gate valve is opened. In this manner the chamber may be evacuated to operating pressure in less than 20 minutes.

CORRECTION OF THE MAGNETIC FIELD.

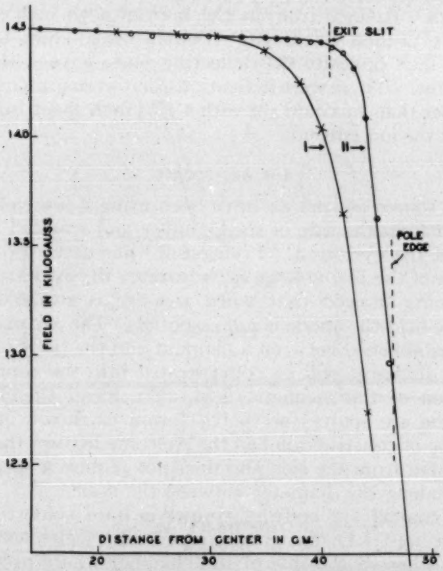
The first visual evidence of resonance was the appearance of an ion sheet in the median plane of the dees. The accelerated ions were first detected with a fluorescent screen placed inside the chamber beyond the deflecting plate. A weak beam of protons was obtained at once. The narrowness of the beam indicated too much magnetic focusing and efforts were made to correct for this by adding shims around the edge. Even large quantities of iron placed symmetrically near the edge as well as radial shimming failed to improve the beam. Field measurements made with a differential flip coil showed a 5 per cent. drop in the field at the exit slit. The insertion of ring shims $5/16'' \times 3/8''$ inside the chamber as described by Rose [8] improved the uniformity of the field to less than 1 per cent. drop at the exit slit as shown in Fig. 7. The dimensions found experimentally that will produce the flat field shown by the curve give a cross section for the ring about twice that found from Rose's curve. The increase in the usable radius of the magnetic field is apparent from Fig. 7. With a pole radius of 46.4 cms. the position of the exit slit at 40.4 cms. is about the maximum possible with the present air gap. The Rose shims were cut to length to fit tightly without

[8] Rose, *Phys. Rev.*, 53, 715 (1938).

support inside the chamber wall in contact with the cover plates.

With these shims in position the addition of various sized circular shims accurately centered improved the beam intensity. Any great dissymmetry in the shimming iron reduced

FIG. 7.



The magnetic field near the exit slit. Curve 1 is the uncorrected field. Curve 2 the magnetic field after the insertion of the Rose shims $\frac{1}{2} \times \frac{1}{16}$ inches.

the beam energy although frequently increasing the current quite markedly. In this way strong beams with energies too low to penetrate one-thousandth inch of aluminum were obtained. A very critical factor in the final shimming turned out to be the bending of the 1 1/4 inch steel cover plates of the chamber. Atmospheric pressure bends the bottom plate 0.005 inch and the top plate 0.042 inch. When the magnetic field is

on this bending is in part straightened out. By changing the tension on long tapered wedges overlapping at the center, the amount of bending can be changed appreciably when the field is on. This was found to have a tremendous effect on the beam intensity. The final circular shims that gave the greatest beam intensity with the tapered wedges adjusted for optimum current are as follows: on top discs of 18, 24, 30 inches diameter of 1/64 inch iron; in the bottom a 30 inch diameter disc of 1/32 inch thickness. A small radial shim 12″ × 3″ × 1/32 inch opposite the deflecting plate gave a slight improvement. There were indications that even a more gradual field taper than we could get with a 1/64 inch sheet iron would improve the ion current.

THE ARC SOURCE.

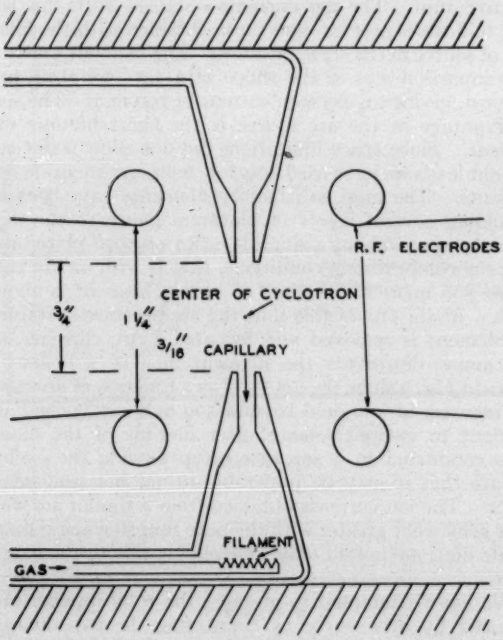
As a source of ions we have been using a low voltage arc mounted from the side of the chamber and situated near the center of the cyclotron. Livingston [9] has described the application of the low voltage arc source to the cyclotron. His experiments showed that when the arc is situated in the magnetic field the anode is not essential. The arc may therefore be established between a filament and the body of the arc and the discharge will be concentrated into the capillary by the action of the magnetic field. We have, therefore, designed the arc source for the cyclotron as shown in Fig. 8. This type of construction has the welcome feature that it can be mounted from the side and does not require a special port directed along the diameter between the dees.

The conical arc body of copper is hard soldered to the end of a 3/4″ I.D. flattened copper tube which extends to the mounting on the side of the chamber where provision is made for moving the arc parallel and perpendicular to the edge of the duants. The source, when rotated through a right angle, will pass underneath the dee. Through the copper tube run insulated filament leads and through it also gas is introduced to the arc. A similar cone is mounted from the top to avoid the dissymmetry of the electrical field between the dees caused by the lower cone alone. Water cooling pipes of 3/16″ copper tubing are soldered to the sup-

[9] Livingston, *Rev. Sci. Inst.*, 10, 63 (1939).

porting arm and around the conical arc body. The nose of the cone is fitted with a 3/16″ threaded hole into which may be screwed a short copper screw pierced with the desired size of capillary. The best size of the capillary is found experi-

FIG. 8.



The arc source.

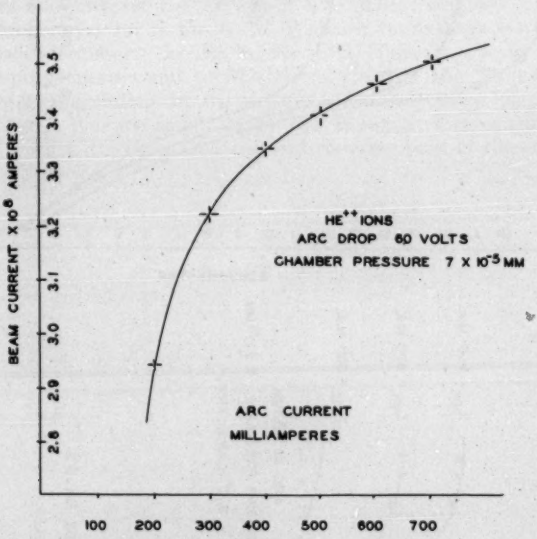
mentally and must be such that the gas pressure in the arc gives a stable discharge and the chamber pressure is not so high that the ions being accelerated are removed from the beam by collision. The ion yield increases with the size of capillary up to the 3/16″ diameter which is the largest that

has been tried. In working with helium where the gas consumption is not important, we have been using the 3/16″ capillary. We have no measure of the gas pressure in the arc, but it is still sufficient to give a stable discharge in helium at chamber pressures ranging from the optimum value of 7×10^{-5} mm. (ionization gauge reading) down to as low as 3×10^{-5} mm. The ion currents obtained with this source are 5 to 6 times greater than those obtained with the filament type of source in the same position. The filament source used for comparison was in the shape of a 1/2″ spiral of 30 mil. tungsten, giving an electron current of 700 m.a. The serious disadvantage of the arc source is the short lifetime of the filament. Since space limitations did not allow water cooled filament leads we have used only low temperature oxide coated filaments. The most satisfactory filaments have been made by folding several layers of platinum gauze to the desired size or by spot welding a single layer to a 0.002″ platinum foil. Under normal running conditions, that is with an arc current of 400–500 m.a., the lifetime of such a filament is about 25 hours. At the end of this time the arc becomes unstable and the filament is removed and recoated. Arc currents of 1.5 to 2 amps. deactivate the filament in 4 or 5 hours. The curves in Fig. 9 show the ion yield as a function of arc current. The increase in ion yield beyond 500 m.a. arc current is not sufficient to outweigh the shorter lifetime of the filament. Tests conducted in a separate setup outside the cyclotron indicate that it may be preferable to use hot tungsten filaments. The ion currents obtained from a similar arc were as a rule somewhat greater with the pure tungsten spiral filament and its lifetime limited only by buckling due to the magnetic forces.

We have attempted to measure the total number of ions produced by this source by connecting the two duants together and to a source of D.C. voltage. The current collected when the dees are made negative, that is, the total ion current, is shown in Fig. 10 for different arc currents. The curves show a flattening in the region of 8 K.V. and the radio frequency voltage of 25 K.V. should therefore collect the maximum number of ions. Apparently we have available from the ion source very large ion currents. The fact that

we accelerate such a small fraction of them in the ion beam may mean that most of the ions are not He^{++} or that as the cyclotron is adjusted, it is focusing the ion beam far from perfectly. An independent investigation is in progress to determine the nature of the ions produced by this type of source.

FIG. 9.



The He^{++} beam current as a function of arc current.

PERFORMANCE.

The cyclotron equation with the chosen values of magnetic field and radius to the exit slit yields 16.5 million volts for He^{++} ions. Visual observations of the beam in air after it had passed through a one-thousandth inch aluminum window gave a range corresponding approximately to this energy of the α-particles. The beam current of 1/30 microampere is concentrated in an area 0.7 cm. $\times$ 3 cms.

FIG. 10(b).

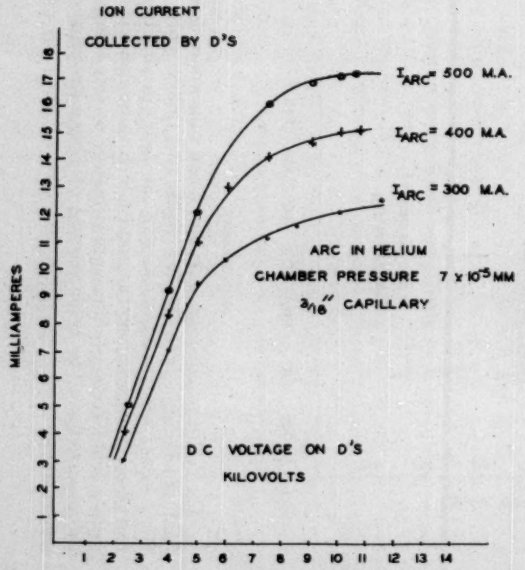
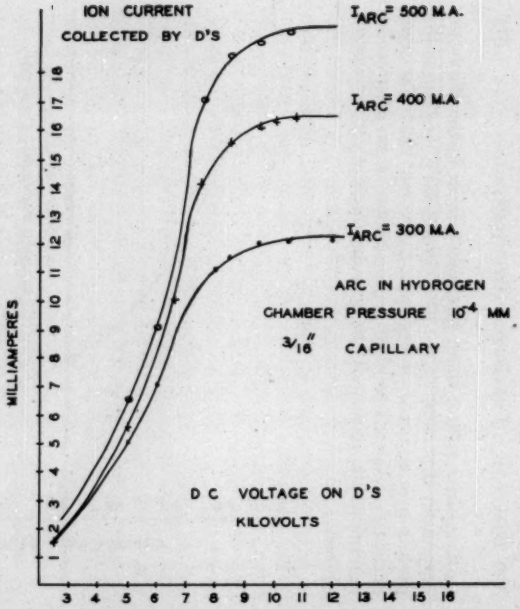


FIG. 10(a).



The ion current collected by a D.C. voltage on the dees. (*a*) Hydrogen arc. (*b*) Helium arc.

The water shielding has not yet been installed and because of the high neutron background we have been limited to short runs with the deuteron beam. The current obtained has been 3 microamperes at 8×10^6 volts.

The successful completion of the cyclotron has been due to the cooperative efforts of several persons. We wish first to express our thanks to Dr. K. Lark-Horovitz through whose efforts and interest the cyclotron was made possible. Our thanks are also due to Dr. R. M. Whitmer for assistance with the radio frequency circuits, to Mr. J. O. Hancock who wired the control panels and to Mr. H. A. Hurd of the Shop for valuable suggestions in the design and construction of the chamber. We are indebted to the Research Corporation, New York City, for a Grant-in-Aid covering part of the cost of construction.

Air Conditioned Blast Furnace.—(*Refrigerating Engineering*, Vol. 38, No. 2.) Construction of an air conditioned blast furnace is under way at the Woodward Iron Co., Woodward, Alabama, in a move watched by iron and steel manufacturers throughout the United States to determine if this method of producing better pig iron is successful from an economical and practical standpoint. H. A. Berg, president of the iron company, said the object of the experiment is to control the amount of moisture in the air in an effort to obtain greater uniformity in pig iron. The Carrier Corporation of Syracuse, N. Y., will air condition a blast furnace now being modernized. The installation calls for refrigeration and air conditioning equipment to control the amount of moisture in the air handled. Twenty-seven hundred tons of air per day are cooled to a constant predetermined dew point, then heated to a temperature of 1000° F. with no water added. A daily average of twenty tons of water is removed from the air.

R. H. O.

New Mineral.—Discovery of a new mineral, officially named "shortite" was announced recently by the Geological Survey, Department of the Interior. Composed of a double carbonate of sodium and calcium, the new mineral was found and identified by J. J. Fahey, chemist, in the Geological Survey laboratory. It was discovered as disseminated well-formed crystals in sections of core from the John Hay oil and gas well, drilled by Mountain Fuel Supply Company on leased Government land in Sweetwater County, Wyoming, at depths of 1,250 to 1,800 feet below the earth's surface. Shortite was named in honor of Dr. M. N. Short, a former geologist of the Survey who now is Professor of Optical Mineralogy at the University of Arizona. Although the commercial value of "shortite" is not yet definitely known, the new mineral is associated with considerable quantities of trona, sodium carbonate-bicarbonate, which does have potential commercial value. Trona was identified in a sample from this same well in 1938 by R. C. Wells, chief chemist of the Geological Survey. The new find probably will be one of the few mineral discoveries for the year. So thoroughly has the earth been combed that, during the past two years only about twenty new minerals were discovered in the entire world.

R. H. O.

RADIO IN NAVIGATION.

BY

C. D. TUSKA,

Patent Department, Radio Corporation of America.

(*Concluded from October issue.*)

AUTOMATIC RADIO BEARING INDICATORS.

In the foregoing direction finding systems the bearing information is obtained by manual operation; the directional antenna or goniometer is rotated by hand until the minimum signal is observed. An automatic method would be more useful. As early as 1917 Artom [47] proposed a directly readable instrument. The device employed crossed coils in a fixed magnetic field. The coils were connected to rectifiers, which were coupled to the direction finding system. Since the currents applied to the coils corresponded to the electromotive forces induced in the directional system, the resultant coil position was a function of the direction of the waves inducing the forces. The system described was not adapted to 360° bearing indications.

Goldschmidt and Braillard [48] were among the first to suggest a practical direct reading radio bearing indicator. The instrument includes, in addition to a conventional radio receiver, a loop antenna, a transparent cylindrical bearing scale, and a galvanometer. The loop antenna and scale are rotated in synchronism at ten revolutions per second by a suitable motor. The galvanometer is positioned within the cylinder so that light reflected by the galvanometer mirror traces a line on the scale. If no signals are received, the position of the line remains unvaried; if a signal is received, the line indicates maximum and minimum response points, whereby the bearing may be read directly. The proposed system can be made either unilateral or bilateral by employing or omitting a "sense" antenna to obtain cardioid or figure-of-eight directive characteristics.

August Leib [49] proposed a direction finder in which the loop and scale are synchronously rotated. The scale is illuminated by a neon tube, which is connected to the receiver output circuit. When the maximum signal is received the neon light will be illuminated. Thus the scale is stroboscopically illuminated to indicate the bearing. Leib also suggested [50] that a relay for controlling the motor may be substituted for the neon light. In this manner the loop may be automatically oriented to a maximum or minimum signal response by the relay controlled motor which orients the loop. This concept has been carried forward in a self-orienting radio compass recently announced by Sperry-RCA.[51]

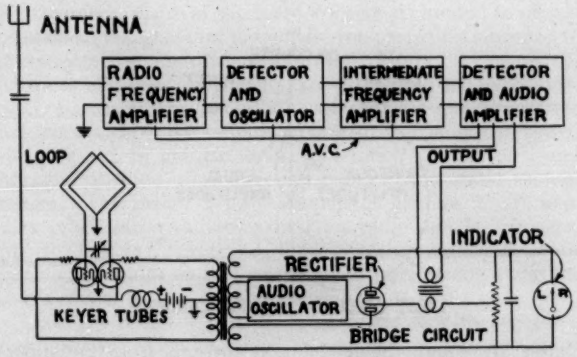
Henri Busignies [52] has described a radio compass in which an antenna is alternately connected to a pair of crossed loops so that a pair of cardioid response patterns are obtained. The receiver output is synchronously connected to first one then the other of a pair of meter coils. The effect of this four-fold commutation is to rotate the response pattern around the antenna. The meter coils, which are fastened together, assume a position corresponding to the direction of propagation of the received wave, and a suitable pointer indicates the wave source.

In a U. S. patent [53] entitled "Magnetic and Radioelectric Goniometry," Lucien Levy discloses an interesting type of radio direction finder. A loop and alternator armature are rotated in synchronism. The currents derived in the output of a receiver, connected to the loop, have a phase which is a function of the wave front intercepted by the loop. The alternator phase is fixed with respect to the loop. If the phase displacement is measured, the phase angle is a function of the radio bearing. In a modification of this system, Levy describes (53) an arrangement in which crossed loops are alternately keyed by currents corresponding to $\sin \omega t$ and $\cos \omega t$. These currents, being independent of the direction of the received signals, are used as a reference phase. The phase of the received signals, after demodulation, is compared to the reference phase to indicate the radio bearing.

The Levy disclosure has been improved by Dieckmann,[54] Berndorfer,(54) Hell,[55] Scheppmann [56] and others. The improvements have resulted in a "Left-Right" meter. The

Left-Right meter has had wide-spread use in aircraft in the United States. The device indicates whether the craft carrying the instrument is headed to the left or right or on a desired course. The essential circuit elements of a left-right indicator are shown in the accompanying diagram, Fig. 4. The non-directive antenna is coupled to the input circuit of a superheterodyne which includes an automatic volume control circuit (*AVC*). The output circuit includes an output transformer, which is symmetrically arranged with respect to a bridge circuit connected to the "Left-Right" indicator.

FIG. 4.

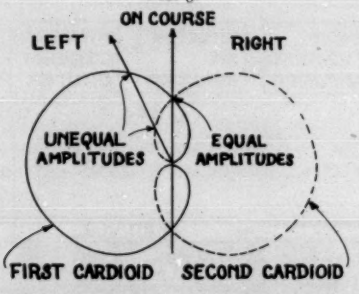


The directive antenna is a shielded loop which is symmetrical with respect to its grounded mid-point. The loop is connected to the input circuits of a pair of push-pull connected keyer tubes. The output circuits of the keyer tubes are coupled to the input circuit of the superheterodyne. The input of the keyer tubes is also connected through a transformer to an audio oscillator, which synchronously applies currents to the keyer tubes and to a full wave rectifier symmetrically connected to the bridge circuit.

The operation is essentially as follows: The audio currents applied to the rectifier flow through the bridge circuit in alternately opposite directions. The alternations are so rapid

that no indication is given by the indicator. The loop radio frequency currents, modulated by the keyer circuit, are of two phases which alternately add to or subtract from the antenna radio frequency currents. The combined currents are amplified, demodulated by the superheterodyne, and applied to the output transformer and rectifier. The current thus applied either adds or subtracts from the currents applied to the bridge circuit to produce an unbalance. The unbalance is indicated by a "left" or "right" deflection of the indicator needle. The deflection to the left or right is a function of the phase of the loop currents which depends upon the loop orientation. If the loop currents of opposite

FIG. 5.



phases are equal, the modulation currents from the superheterodyne output will be equal and opposite and therefore will have no effect on the indicator. Thus, "on course" is shown; while "off-course" is indicated by left or right deflections.

Another way of viewing the operation is to consider that the loop currents alternately combine with the antenna currents to establish a first cardioid pattern and a second cardioid pattern. The synchronous application of the audio oscillator currents—for keying the loop and energizing the bridge circuits—"identifies" which cardioid is in operation. With the cardioid "identified," the sense of the deviation (i.e., "left-right" course departure) can be indicated as shown in the accompanying diagram, Fig. 5. It should be

understood that in place of the rectifier and bridge circuit, a dynamometer type of meter may be operated on the two alternating currents to indicate the left-right course departures.

Thus, we have traced the historical, technical and practical development of *directional receiving devices*. Before directing our attention to some of the practical applications of radio in navigation, let us turn back to consider directive transmitters, or radio beacons, as they are often called.

RADIO BEACONS.

Most of the pioneers recognized that directional receiving antennas, if suitably energized, became directive transmitters. Furthermore, many of the early workers attempted to obtain directional transmission to increase the operating range, or to investigate the scientific possibilities. Hertz [1], [2] used cylindrical parabolic mirrors to direct the transmitted waves. S. G. Brown [4] was certainly aware that his spaced antenna produced a directive radiation pattern, and he also renewed the proposal to use parabolic reflectors.[57] Stone [5], [58] and Marconi [7] knew that directive transmission could be obtained. The Bellini & Tosi Goniometer systems [23], [24] were very practical for radiating directive radio signals. In 1900 M. R. Garcia [59] proposed that directive transmitters be installed on ships so that waves could be sent out along the ship's course to act as a warning signal.

Lee De Forest [60] may have been the first to suggest a radio beacon, which he named "Aerophore." The Aerophore includes a radio transmitter which was connected to a directive antenna. One suggested antenna was patterned after Hertz's dipoles and reflector; another was an inclined aerial. The antenna array was rotated about a vertical axis. During the rotation, distinctive and beam-like signals were sent at sixteen compass points. Another set of characteristic signals were transmitted to identify the beacon and its location. The operator of a non-directive receiver responsive to the beacon could observe the maximum signal and hence the bearing of the receiver with respect to the "Aerophore."

The rotating radio beacon has remained an attractive goal for experimenters. Andre Blondel [61] revived the idea in 1913, called the beacon a "Hertzian Lighthouse," and

disclosed a system not greatly different from De Forest's. The Germans went one step further than De Forest and Blondel. A U. S. Patent [62] to Alexander Meissner discloses a rotating radio beacon in which a directive beam is radiated along successive radials at a constant rotational velocity in a, say, clockwise direction. A non-directive signal is sent out at the instant before the beam points in a predetermined direction, for example, north. The operator who wishes to determine the bearing of a receiver, is provided with a stop watch which operates at the same rotational speed and direction as the rotating beacon signal. The operator starts the watch when he hears the non-directional reference signal and stops the watch when he observes the maximum beam signal. The watch is calibrated to indicate bearings directly.

The English were also active in the development of rotating radio beacons. In the *Journal of the Institute of Electrical Engineers*,[63] J. Erskine-Murray and J. Robinson describe a rotating beacon which differs from the prior beacons. The Meissner beacon depends upon the ability of the operator of the receiver to pick out the maximum signal as the beacon sweeps past the receiver. This may be difficult to distinguish. The Erskine-Murray and Robinson system avoids this difficulty. In their device two crossed directive antennas are rotated at one revolution per minute. The radio currents are applied to one antenna continuously in one sense and to the other antenna in a sense reversed two to four times per second. The operator of a non-directive receiver listens for two signals of equal strength. While this indicates the bearing, it would appear that there may be ambiguity with respect to four sets of equal fields disposed at right angles.

In 1920 an experimental short wave rotating radio beacon was installed at Inchkeith.[64] In the Inchkeith beacon the transmission was on a wave length of four meters, i.e., a frequency of seventy-five million cycles per second. The rotating beam was obtained by rotating a reflector about the radiator once every two minutes. A distinctive signal was transmitted at every half point of the compass card. The range of this short wave beacon was seven nautical miles.

Franklin [64] states that the accuracy was equal to one-quarter compass point or 2.8°.

The British continued the development of rotating radio beacons.[65, 66, 67] In an article [65] by Gill and Hecht entitled "Rotating-Loop Radio Transmitters and Their Application to Direction-Finding and Navigation," the system is described as a loop which is energized and rotated at 1 R.P.M. The loop signal is interrupted at the instant when its minimum signal is transmitted at true North; at this instant a special Morse signal is transmitted so that an observer can time the interval from the true North signal to the instant when the minimum of the rotating signal pattern reaches the observer's instrument. The authors report accuracy of 0 to 5° for the majority of observations and a maximum error of 15°.

Tests of the British Air Ministry rotating beacon reported by Smith-Rose and Chapman [66] indicate excellent results. The permanent deviation of the beacon appeared to be 1° to 2°. Up to a distance of sixty miles, the bearings agreed with bearings taken by other methods. Within this distance the maximum error was 5°, and in seventy per cent. of the observations the accuracy was within 2°. Bearings taken on ships anchored 90 to 100 miles away were accurate to within 4°. Beyond 60 miles night observations indicated variations of about 18°. Fair accuracy was obtained at night by averaging bearing readings taken over ten or fifteen minute periods. The authors conclude that the beacon bearings were more accurate than ordinary direction finder bearings taken on ships in a rough sea.

Although the foregoing types of rotating radio beacons are automatic as far as the transmission is concerned, bearing observations depend to a large extent upon the operator's skill. Furthermore, several observations of each bearing may be required. Thus both skill and time are essential to the accurate determination of bearings. When employed in marine navigation the foregoing requirements are usually met because skilled operators are available and time is not of the essence on a vessel moving at speeds usually below thirty knots.

When beacons of the type described are used in the navigation of modern aircraft, new problems are encountered.

The commercial aircraft in the United States do not usually carry a radio operator. One of the pilots performs the radio duties. Modern airplanes cruise at velocities of three to four miles a minute. It may take two minutes to take a bearing; during the taking, the craft may have gone six or more miles. Erroneous bearings are being created while they are being obtained!

Recognizing these difficulties engineers in the United States have approached the problem in two ways. One is a fully automatic type of rotating beacon; the other is a radio range which established courses or radio airways. The former has not come into general use but offers great promise; the latter is in general use. One form of rotating beacon employs four Adcock antennas, which are located at the corners of a square. A non-directive antenna is located at the center of the square. The Adcock antennas are energized by radio frequency currents in quadrature phase, whereby a rotating field is established. The rotating field may be viewed as a cardioid rotating at its zero point about the central antenna. The central antenna is also energized by the radio frequency currents so that a non-directive field is created. A reference signal is impressed on the non-directive antenna at the instant when the maximum of the cardioid pattern passes through North. Thus two fields are established: one non-directive and bearing a reference signal; the other rotating about the beacon.

The receiver requires a non-directive antenna in its input circuit and a phase indicator in its output circuit. The operation is as follows: A sinusoidal electromotive force is induced in the receiving antenna by the rotating field. This force is used after suitable amplification to drive the phase indicator, which may be for example the cathode ray of a cathode ray tube. The non-directive field, bearing the reference signal, will also be received and amplified. The phase relation of the reference mark to the sinusoidal current will depend upon the bearing of the receiving antenna with respect to the beacon. For example, due North of the beacon the maximum of the rotating field will coincide with the reference mark. For clockwise field rotation, the reference mark will be 90° ahead of the maximum, when observed due

east of the beacon. At due south the phase will be 180°; at due west the phase will be 270°. At intermediate compass points intermediate phases will be indicated.

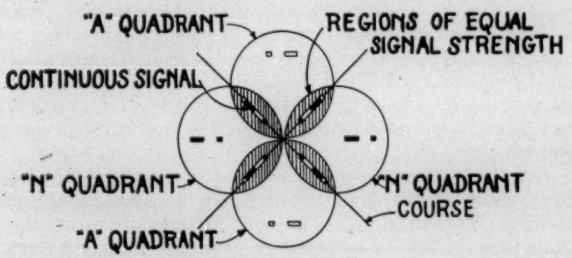
The foregoing automatic rotating beacon system provides continuous and direct bearing indication. The phase meter may be calibrated as a compass card. No special skill is required as the bearings are indicated automatically. Each beacon provides an infinite number of fixed radial courses for aircraft. There is no ambiguity in the indicated courses. In the United States P. H. Evans,[68] J. W. Greig,[69] George H. Brown,[70] C. R. England,[71] C. W. Hansell,[72] D. G. C. Luck [70] and others have contributed to the fully automatic beacon system.

While the rotating beacon was in the process of development, the present system [73] of networks of radio ranges grew up in the United States. The radio airways are established along commercial routes between all of the principal cities. Radio markers are used to indicate fixed positions on the routes. The first radio ranges used in the United States are described in an article entitled "A Directive Tube Radio Beacon and Its Application" by F. H. Engel and F. W. Dunmore.[74] A pair of transmitting loop antennas were arranged at an angle of 135° with respect to each other. A Morse A (dot dash) signal from a radio transmitter was impressed first on one loop and then a Morse T (dash) on the other; the change was made once every second. The radiated waves formed overlapping figure-of-eight fields. The region of overlap was characterized by the reception of equal signals from the two coils. The equisignal region was located on the bisectors of the angles at which the loops were crossed. A conventional radio receiver was used to follow the course established by the overlapping fields.

The experimental work by Engel and Dunmore took place about 1921 at the Bureau of Standards, and was later transferred to McCook Field, Dayton, Ohio. The engineers of the U. S. Army Air Service coöperated in developing and testing the radio range.[74] The angle of loop intersection was changed to 90°. The Morse signals were changed to A (·—) and N (—·), which were interlocked. The dash of the N was timed to start immediately after the dot of the A and the

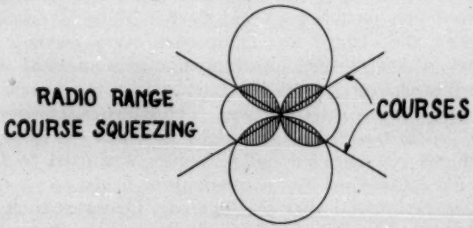
dash of the A followed the dash of the N. Likewise the dot of the N followed the dash of the A. The nature of the field patterns and signals is shown in Fig. 6. In the equisignal region a continuous long dash is heard in the earphones of a

FIG. 6.



conventional receiver tuned to the beacon. On the respective sides of the equisignal region an A or a N signal predominates. Four equisignal regions are established. One or more of these regions are made to coincide with the desired course or courses.

FIG. 7.

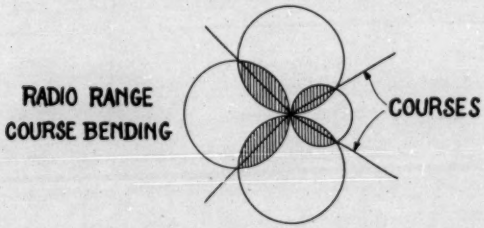


Since radio courses intersecting at 90° do not always align with the desired geographic courses, it was desirable to be able to shift or adjust the angles of the intersecting courses. This became known as "squeezing" or "bending." If the strength of one of the figure-of-eight fields is greater than the other as shown in Fig. 7, the courses are squeezed together. If

circular radiation is added to one of figure-of-eight fields to distort the field pattern as shown in Fig. 8, the courses are bent. Suitable methods of making such adjustments have been disclosed.[75, 76]

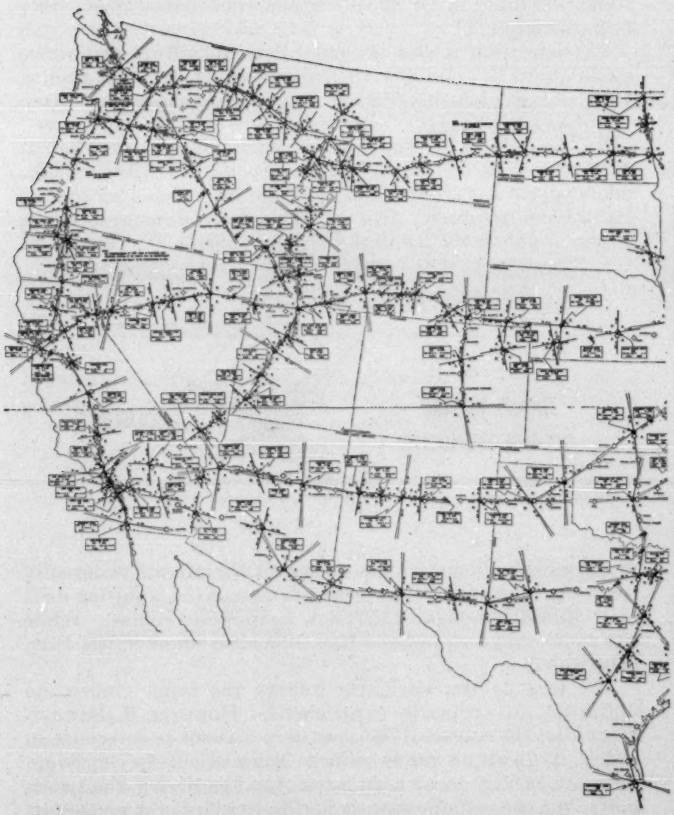
At one time it was proposed [77] to substitute distinctive modulations of two different frequencies for the A–N keying. With the double modulation it was possible to substitute vibrating reeds for telephone receivers to indicate "off course" and "on course." The use of characteristic modulation makes six or twelve course beacons practical.[78] However, the pilots appear to favor aural signals and more than four courses are seldom required. One of the great advantages of an airway course is the freedom from drift effects.(74) In the use

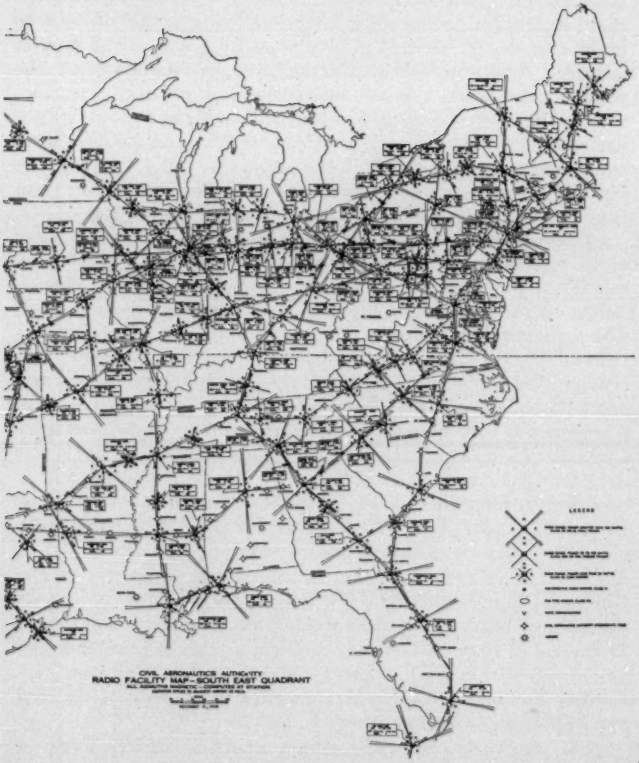
FIG. 8.



of an ordinary homing radio device an aircraft will eventually reach the transmitter but cross winds and the resulting drift may cause the navigator to follow a circuitous course. While the radio range eliminates this difficulty, another has been substituted.

As long as the navigator follows the range course, no difficulties are ordinarily experienced. However, if the navigator loses the course, it becomes very difficult to determine in which A quadrant or in which N quadrant he is flying. Suggestions [79, 80] have been made for identifying the quadrants, but the complication is hardly justified. A navigator, uncertain as to which of the several radio range courses he is following, can check his position by employing a conventional direction finding receiver. The position can be fixed by




CIVIL AERONAUTICS AUTHORITY
RADIO FACILITY MAP - SOUTH EAST QUADRANT
LEGEND

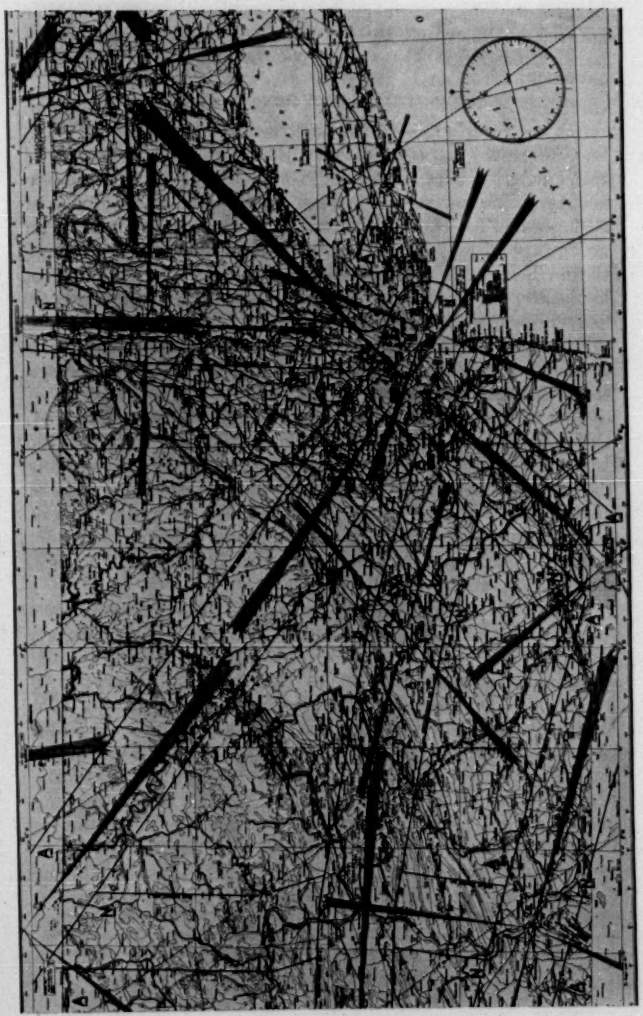
bearings obtained from two or more radio transmitters operating at known positions.

The daylight effectiveness of the radio ranges was well established by 1927 but night operation was a matter of uncertainty. Haraden Pratt [81] made a series of tests of the night operation of the radio range and found shifting due to night effects. Within 25 miles the shifting was not of serious nature. At 50 miles the shifting was pronounced but the beacon was usable. At 100 miles the beacon was of questionable value, and beyond 125 miles the beacon was of no further use. This pronounced night effect appeared to be due in no small part to the use of loop antennas for reception. A vertical receiving antenna apparently offered some relief from range night effects.

The vertical receiving antenna was not a cure for these night effects. The radio ranges employed loops for transmitting. The loop range courses showed severe night effects. These effects were most deleterious in mountainous country.[82] The range-beacon courses were of doubtful value beyond thirty miles during night operations. Adcock-type antennas [(44)] were substituted for the radio range loops, and comparison tests were made. The courses established by loop transmission varied as much as $\pm 45°$; the courses created by the Adcocks seldom varied $\pm 2°$. This interesting work was done in 1931 under the direction of Harry Diamond and is reported in his paper "The Cause and Elimination of Night Effects in Radio Range-Beacon Reception." [(82)] Practically all of the modern radio ranges are equipped with vertical or Adcock antennas. Persistent work by the engineers of the Bureau of Standards, the Civil Aeronautics Authority and its predecessor has brought the range to a high point of efficiency. In the fall of 1929 only twenty-four radio ranges were installed and in operation within the United States. While on November 1, 1938, the Civil Aeronautics Authority [83] reported 279 radio ranges in operation.

The networks of radio range courses, which were in operation in the latter part of 1938 in the United States, are shown on the accompanying "Radio Facility Map." * The

* Reproduced through the courtesy of the Civil Aeronautics Authority.



nature of the charts used in conjunction with radio range courses is illustrated by the "New York—Sectional Aeronautical Chart." *

PRACTICAL APPLICATION OF RADIO IN NAVIGATION.

In the foregoing sections we have considered the historical and technical aspects of directional radio receivers and transmitters. The use of radio as a means of transmitting accurate time signals was not discussed. The transmission of such signals for the determination of longitude has been an accomplished fact since 1912.[84] If a navigator is employing radio time signals to check chronometers for the reckoning of longitude, the directional characteristics of the radio waves do not enter into his calculations. Furthermore, any of the different types of maps or charts may be used. When a Mercator's chart is used, a rhumb line may be followed for short distance navigation, but if the distance is in excess of two or three hundred miles, a great circle course is followed. On a Mercator chart, a rhumb line track is a straight line and a great circle course is a curve. The radio waves follow the great circle course. Therefore, for distances in excess of about three hundred miles, radio bearings or radio lines of position must be corrected.[85] If a gonomonic projection chart is used, the great circle courses are straight lines. Therefore, radio bearings may be applied directly.

Positions are fixed by the intersection of two or more lines of position which may be obtained by directional receivers. Either lines of position or fixes may be obtained by the use of directional receivers located on the craft and operated to indicate the bearings of the receiver by utilizing signals from transmitters at known locations. In like manner the navigator of a craft may request bearings by radio and, by means of directional receivers at known locations, operators observe the bearings of the transmitter on the craft. These bearing observations are communicated to a central receiving station from which the bearings are relayed to the craft. The latter type of compass stations were installed along the coasts of the United States near the principal harbor entrances and operated by the U. S. Navy in 1919.[86] In 1922 the U. S. Navy operated

* Reproduced through the courtesy of the U. S. Coast and Geodetic Survey.

twenty-two radio compass stations [87] which were suitably located for obtaining crossed bearings. The reported accuracy was within 2° of arc.

While the U. S. Navy favored the shore station system of obtaining bearings, the U. S. Department of Commerce [88] preferred to install radio transmitters on the harbor light vessels. These transmitters radiated distinctive signals which could be received by a directional receiver. Crossed bearings obtained from the radio fog signals proved very useful and quite accurate. The U. S. Commissioner of Lighthouses, George R. Putman, in his paper—"Radio Fog Signals" [(88)]—cites reports from the officers of the S. S. "H. F. Alexander," S. S. "Belgenland," S. S. "Majestic," S. S. "Paris" and other vessels praising the system and describing the use of the signals in navigation. When the bearings are obtained by means of directional apparatus on the craft, the radio reception is not limited to radio lighthouse stations but any radio transmission from known sources may be used. By selecting suitable sources the accuracy of the fixes obtained by triangulation may be increased. Another advantage of obtaining bearings by means of a directional receiver on the craft is that responsibility for the bearings rests on the navigator and is under his control. In time of war the operation of a transmitter on a craft requesting bearings may indicate the craft's position to the enemy. The directive reception system on the craft does not convey any information to the enemy.

In the preceding sections a few examples of the utility of radio in navigation were given; a few more from Mr. Putman's report may be of interest: A Norwegian steamer "Onataneda" was disabled and in an SOS call gave a position 90 miles in error. Vessels going to the rescue were unable to locate the disabled ship. One, "Fanad Head," was equipped with a radio direction finder and by its use was able to locate the "Onateneda."

A British steamer "Lord Strathcona" sent out distress signals. An American ship, "W. M. Burton," was assigned to the rescue, but fog prevented sighting the vessel. Another British ship, "Cassandra," by means of its radiocompass, was able to obtain bearings of the two ships and thus direct the "W. M. Burton" to the rescue.

The steamer "Presidente Wilson" rescued the crew of the freighter "Guibia" by obtaining radiocompass bearings of the sinking freighter. The Italian passenger liner "Conte Rosso" located the S. S. "Eastern King," notwithstanding dense fog, by using her radiocompass and took aboard a seaman badly in need of expert medical attention. The Coast Guard cutter "Tampa" quickly located the British steamship "M. S. Dollar," which was disabled. The radiocompass has saved much time in the Coast Guard rescue work. A number of other examples of radio direction finding aiding in rescue work at sea have been published.[89]

Radio has played a very important part in many of the pioneer long distance flights of aircraft. The famous flight of Adcock and Brown from St. Johns to Cliften, Ireland, shortly after 1918 was aided by homing radio direction finding on the radio station at Cliften.[90] The distinguished Transatlantic flight of the U. S. Navy's NC4 employed radio as a navigation aid.[91, 92] Radio played its part in Commander Byrd's famous flight from the United States to France.[93] Byrd's plane "America" had a radio transmitter which automatically sent the plane's call letters "WTW" when the operator was otherwise engaged. Radio direction finders followed the course of the "America." Early in 1920 a U. S. Navy flying boat of the N-16 type was given the task of locating the battleship "Ohio" which was 100 miles at sea in an unknown direction.[(93)] Immediately after taking off from Hampton Roads, the bearing of the "Ohio" was obtained by the directional radio on the plane and the "Ohio" was located inside of an hour.

The value of radio ranges in air navigation was demonstrated in 1927 in the flights from California to the Hawaiian Islands. The entire Hawaiian Island group subtends an angle of 7 degrees at San Francisco. A course error of 3½ degrees might lead to an aircraft flying past the islands. Before the U. S. Army attempted its flight, radio beacons were installed at San Francisco and Maui.[94] The beacon course was checked on the S. S. "Manoa." During favorable conditions the beacon signals from San Francisco could be heard on the islands and vice versa. At the midpoint between the beacons, the course was estimated to be about seven miles wide and

it converged as Maui was approached. On June 28 and 29, 1927, Lieutenants Hegenberger and Maitland made the flight in a Fokker Monoplane Type C-2. The radio range was used during only part of the flight because of receiver difficulties.

On July 14–19, 1927, Smith and Bronte in the monoplane "Travel Air" started from San Francisco and landed at Molokai. They used the radio course until their headphones went out of commission.[94] The radio beacons were operated by the Army to assist the participants in the Dole Flight from San Francisco for Hawaii. The flight started on August 16, 1927. Goebel and Davis in the monoplane "Woolaroc" were the winners. In expressing his appreciation of the beacon service, Lieutenant Davis wrote:—". . . In particular, the radio beacon was an unqualified success, and rendered the navigational problem a very simple one. The signals were clear and distinct and were held practically the entire way. At one time I was able to hear both the San Francisco and Maui beacons at the same time, our position at the time being about midway between Honolulu and San Francisco." [94]

The use of radio in these spectacular flights and rescues should not detract from the routine use of radio in the navigation of surface vessels and aircraft. In the latter class of service, thousands of miles of radio airways are operated twenty-four hours every day in the year for the safety of passengers, crews and property.

CONCLUSIONS.

Although the directional properties of electromagnetic waves were discovered by Hertz in 1888, radio direction finding developed very slowly until the World War. The wartime demand brought forth radio compasses of increased range, reliability, and accuracy. As is so often the case, the devices designed for war found a greater utility in peace. The radio polorus became, before long, an accepted element of marine and aircraft equipment. Radio has proven especially useful in obtaining lines of position and position fixes during periods of low visibility when other navigational aids were practically inoperative.

The advent of high speed air transportation brought new requisitions for better navigation. These latest requirements

were met by establishing radio courses between airports. The radio courses have been so helpful that the United States has been covered with a network of radio airways. Modern air travel would be impractical during adverse weather conditions without the aid of radio. It has been difficult to follow a radio course or to take accurate bearings at night. Observations indicate that wave reflections from the Kennelly-Heaviside Layer may account for the "night effect" in direction finding. Various solutions of this difficulty have been presented and others will be proposed as the endless search for perfection continues.

ACKNOWLEDGMENT.

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BIBLIOGRAPHY.

1. *Annalen der Physik und Chemie* (Wiedemann's Annalen), **34**, 155–1888.
2. Electric Waves. Hertz. Translated by D. E. Jones, 1901, p. 86.
3. A History of Wireless Telegraphy by Fahie, Second Edition, 1901, 217 et seq.
4. British Patent No. 14,449 of 1899 to S. G. Brown.
5. U. S. Patent No. 716,134, issued December 16, 1902, to John Stone Stone.
6. *Proc. Royal Society*, **77**, 413.
7. British Patent No. 14,788 of 1905 to G. Marconi.
8. British Patent No. 3,127 of 1906 to G. Marconi.
9. U. S. Patent No. 924,168. Issued June 8, 1909.
10. Principles of Radio Transmission and Reception with Antenna and Coil Aerials. By J. H. Dellinger. Scientific Papers of the Bureau of Standards, **15**, 435–495.
11. The Radio Compass. By Ballentine. Year Book of Wireless Telegraphy and Telephony, 1921, 1131–1147.
12. Modern Progress in Radio Direction Finding. By R. L. Smith-Rose. Year Book of Wireless Telegraphy and Telephony, 1923.
13. The Effect of Local Conditions on Radio Direction Finder Installations. By Smith-Rose and Barfield. *Journal of the Institute of Electrical Engineers*, **61**, 1923, p. 179.
14. Directional Wireless Telegraphy in Aircraft. By C. K. Chandler. *Journal of the Institute of Electrical Engineers*, **61**, 1923, p. 803.
15. Wireless Direction Finding in Steel Ships. By C. E. Horton. *Journal of the Institute of Electrical Engineers*, **61**, 1923, p. 1049.
16. The Radio Direction Finder and Its Application to Navigation. By Kolster and Dunmore. Scientific Papers of the Bureau of Standards, No. 428.

17. U. S. Patent No. 1,828,395. Issued October 20, 1931, to Clark and Allen.
18. U. S. Patent No. 1,368,657. Issued February 15, 1921, to H. J. Round.
19. U. S. Patent No. 1,646,443. Issued October 25, 1927, to W. B. Burgess.
20. U. S. Patent No. 1,702,041. Issued February 12, 1929, to Cecil Davis.
21. U. S. Patent No. 1,725,147. Issued August 20, 1929, to F. A. Kolster.
22. U. S. Patent No. 1,868,982. Issued July 26, 1932, to F. H. Kroger.
23. British Patent No. 21,299 of 1907, U. S. Patents 943,960 and 945,440.
24. French Patent No. 387,933, March 7, 1908, U. S. Patent 948,086.
25. U. S. Patent No. 876,996. Issued January 21, 1908, to G. W. Pickard.
26. U. S. Patent No. 771,818. Issued October 11, 1904, to Lee De Forest.
27. Static Elimination by Directional Reception. By G. W. Pickard. *Proceedings of the Institute of Radio Engineers*, **8**, No. 5, p. 358.
28. Direction and Position Finding. By H. J. Round. *Journal of the Institute of Electrical Engineers*, **58**, 1920, p. 224.
29. The Daylight Effect in Radio Telegraphy. By A. E. Kennelly. *Proceedings of Institute of Radio Engineers*, **1**, No. 3, p. 39.
30. The Heaviside Layer. By E. W. Marchant. *Proceedings of Institute of Radio Engineers*, **4**, No. 6, p. 511.
31. A Suggestion for Experiments on Apparent Radio Direction Variations. By L. W. Austin. *Proceedings of the Institute of Radio Engineers*, **13**, No. 1, p. 3.
32. *Physical Review*, September 1926, Breit and Tuve.
33. *Physical Review*, February 1926, Taylor and Hulburt.
34. Experiments and Observations Concerning the Ionized Regions of the Atmosphere. By R. A. Heising. *Proceedings of the Institute of Radio Engineers*, **16**, No. 1, p. 75.
35. Measurements of the Effective Heights of the Conducting Layer and Disturbances of August 19, 1927. By Dahl and Gebhard. *Proceedings of the Institute of Radio Engineers*, **16**, No. 3, p. 290.
36. Effective Heights of the Kennelly-Heaviside Layer in December 1927 and January 1928. By Breit, Tuve and Dahl. *Proceedings of the Institute of Radio Engineers*, **16**, No. 9, p. 1236.
37. Refraction of Electric Waves. By Eckersley. *Radio Review*, **1**, June 1920, p. 422.
38. Varying Directions of Radio Waves. By Taylor. *Bulletin of the Bureau of Standards*, **15**, July 1919, p. 419.
39. Apparent Night Variations with Crossed Coil Radio Beacons. By H. Pratt. *Proceedings of the Institute of Radio Engineers*, **16**, No. 5, p. 652.
40. Radio Direction Changes and Variations of Audibility. By Kinsley and Sobey. *Proceedings of the Institute of Radio Engineers*, **8**, No. 4, p. 299.
41. The Heart-shaped Polar Diagram and its Behavior under Night Variations. By Wright and Smith. *The Radio Review*, **2**, No. 8, p. 394.
42. The Cause and Elimination of Night Errors in Radio Direction Finding. By Smith-Rose and Barfield. *Journal of Institute of Electrical Engineers*, **64**, 1926, p. 831.
43. The Direction and Intensity of Waves from European Stations. By G. W. Pickard. *Proceedings of the Institute of Radio Engineers*, **10**, No. 3, p. 161.

44. British Patent No. 130,490 of 1919 to Adcock and Ellis.
45. Wireless Direction Finding. By Keen. 3d Edition, p. 674.
46. U. S. Patent No. 2,031,077. Issued February 18, 1936, to Smith and Eckersley.
47. U. S. Patent No. 1,303,625. Issued May 13, 1919, to Alessandro Artom.
48. U. S. Patent No. 1,525,177. Issued February 3, 1925, to Goldschmidt and Braillard.
49. U. S. Patent No. 1,799,238. Issued April 7, 1931, to August Leib.
50. U. S. Patent No. 1,850,080. Issued March 22, 1932, to August Leib.
51. An Automatic Direction Finder. *Communications*, 18, October 1938, p. 10.
52. U. S. Patent No. 1,741,282. Issued December 31, 1929, to Henri Busignies.
53. U. S. Patent No. 1,844,859. Issued February 9, 1932, to Lucien Levy.
54. German Patent No. 517,432, Ausgegeben, February 4, 1932, to Max Dieckmann and Franz Berndorfer.
55. Direktzeigendes funkentelegraphisches Peilverfahren, April 1929, p. 138.
56. U. S. Patent No. 1,961,598. Issued June 5, 1934, to Wilhelm Scheppmann.
57. U. S. Patent No. 741,622 to S. G. Brown. Issued October 20, 1903.
58. U. S. Patent No. 716,135 to John Stone Stone. Issued December 16, 1902.
59. French Patent No. 301,264 to M. R. Garcia. Dated June 14, 1900. U. S. Patent No. 795,762 to M. R. Garcia. Issued July 25, 1905.
60. U. S. Patent No. 833,034 to Lee De Forest. Issued October 9, 1906. U. S. Patent 894,318 to Lee De Forest. Issued July 28, 1908.
61. U. S. Patent No. 1,218,237 to Andre Blondel. Issued March 6, 1917.
62. U. S. Patent No. 1,135,604 to Alexander Meissner. Issued April 13, 1915.
63. Directional Transmission of Electromagnetic Waves for Navigational Purposes. By J. Erskine-Murray and J. Robinson. *Journal of the Institute of Electrical Engineers*, 60, 352 (1922). U. S. Patent No. 1,379,541 to Erskine-Murray and Robinson. Issued May 24, 1921.
64. Short-Wave Directional Wireless. By C. S. Franklin. *Journal of the Institute of Electrical Engineers*, 60 (1922).
65. Rotating-Loop Radio Transmitters and Their Application to Direction-Finding and Navigation. By Gill and Hecht. *Journal of the Institute of Engineers*, 66, No. 375 (1928).
66. Some Experiments on the Application of the Rotating Beacon Transmitter to Marine Navigation. By R. L. Smith-Rose and I. R. Chapman. *Journal of the Institute of Electrical Engineers*, 66, 256 (1928).
67. Radio Direction Finding by Transmission and Reception. By R. L. Smith-Rose. *Proceedings of the Institute of Radio Engineers*, 17, No. 3, p. 425 (1929).
68. U. S. Patent No. 1,933,248 to P. H. Evans and J. W. Greig. Issued October 31, 1933.
69. U. S. Patent No. 1,988,006 to J. W. Greig. Issued January 15, 1935.
70. U. S. Patent No. 2,112,824 to G. H. Brown and D. G. C. Luck. Issued April 5, 1938.
71. U. S. Patent No. 1,815,246 to C. R. England. Issued July 21, 1931.
72. U. S. Patent No. 2,014,732 to C. W. Hansell. Issued September 17, 1935.

73. The Civil Airways and Their Radio Facilities. By H. J. Walls. *Proceedings of the Institute of Radio Engineers*, **17**, No. 12, p. 2141 (1929).
74. A Directive Type Radio Beacon and Its Application. By F. H. Engel and F. W. Dunmore. *Scientific Papers of the Bureau of Standards*, **19**, No. 480, p. 281.
75. Developments of Radio Aid to Air Navigation. By J. H. Dellinger and Haraden Pratt. *Proceedings of the Institute of Radio Engineers*, **16**, No. 7, p. 890 (1928).
76. U. S. Patent No. 1,910,427 to Harry Diamond. Issued May 23, 1933. U. S. Patent No. 1,923,934 to F. G. Kear. Issued August 22, 1933.
77. Development of the Visual-Type Airway Radio Beacon. By J. H. Dellinger, H. Diamond and F. W. Dunmore. *Proceedings of the Institute of Radio Engineers*, **18**, No. 5, p. 796.
78. U. S. Patent No. 1,913,918 to H. Diamond and F. G. Kear. Issued June 13, 1933. U. S. Patent No. 1,992,197 to H. Diamond. Issued February 26, 1935.
79. U. S. Patent No. 1,922,677 to Greig & Bailey. Issued August 15, 1933.
80. U. S. Patent No. 1,992,927 to Francis Dunmore. Issued February 26, 1935.
81. Apparent Night Variations with Crossed-Coil Radio Beacons. By Haraden Pratt. *Proceedings of the Institute of Radio Engineers*, **16**, No. 5, p. 652 (1928).
82. The Cause and Elimination of Night Effects in Radio Range-Beacon Reception. By H. Diamond. *Bureau of Standards Journal of Research*, **10**, No. 513.
83. Tabulation of Air Navigation Radio Aids. Civil Aeronautics Authority Letter, November 1, 1938.
84. Wireless Time Signals. By Arthur R. Hicks. Year Book of Wireless Telegraphy and Telephony, 1913, p. 297.
85. Navigation and Nautical Astronomy. By Dutton, Capt. U. S. Navy. Fifth Edition.
86. Year Book of Wireless Telegraphy and Telephony, 1920.
87. Laws and Regulations, U. S. A. Year Book of Wireless Telegraphy and Telephony, 1921, p. 505.
88. Radio Fog Signals and The Radio Compass. By George R. Putman. Second Edition, 1924.
89. The Marconi Radio Direction Finder. By Donisthorpe. *Proceedings of the Institute of Radio Engineers*, **13**, No. 1, p. 29 (1925).
90. *Wireless Age*, August 1919, p. 18.
91. Across the Ocean on the NC4. By Ensign Herbert C. Rodd. *Wireless Age*, August 1919, p. 13.
92. Naval Aircraft Radio. By T. Johnson, Jr. *Proceedings of the Institute of Radio Engineers*, **8**, No. 2, p. 87 (1920).
93. Aircraft Radio Installations. By Malcolm P. Hanson. *Proceedings of the Institute of Radio Engineers*, **16**, No. 7, p. 921 (1928).
94. Radio Beacons for Transpacific Flights. By C. C. Shangraw. *Proceedings of the Institute of Radio Engineers*, **16**, No. 9, p. 1203 (1929).

Antarctic Cruiser.—The Research Foundation of Armour Institute of Technology has been constructing a mammoth snow cruiser. Duly authorized by the President of the United States and the Director of Territory and Island Possessions, Dr. Ernest Gruening, the snow cruiser will be the main cog in the machinery set-up by the government for the projected Antarctic expedition to lay south polar claims which will get under way some time in October. The snow cruiser will carry four scientists into the very heart of the south polar region with much the same ease and convenience and comfort that one experiences riding in a modern automobile. In fact, the snow cruiser combines all of the comforts of home with the efficiency of one of the Research Foundation's well equipped scientific laboratories for the crew for a period of one year without contact with the outside world, and at the same time carries a five passenger airplane, outfitted as a flying scientific laboratory, on its back. It will have a cruising range of 5,000 miles and have a speed of from 10 to 30 miles per hour depending upon the grade, surface conditions, and weather. Looking like a transcontinental bus, only much longer, the snow cruiser will be 55 feet in length, stand fifteen feet high on ten foot rubber tires and be able to span crevasses fifteen feet wide. Ingeniously designed by its inventor, DR. T. C. POULTER, makes it possible to raise or lower the cabin of the cruiser at will, turn corners practically in its own length, move sideways at an angle, and climb polar mountains, or ride out storms without special precautions. The airplane carried on its back or top deck, can be unloaded and prepared for flight in ten minutes and loaded again in the same short span of time. The cruiser has four electric motors in each of its immense wheels—the motors will be supplied by two Diesel-electric power plants.

R. H. O.

SENSITOMETRY OF PHOTOGRAPHIC PAPERS.

BY

LOYD A. JONES and C. A. MORRISON.*

(*Continued from October issue.*)

SENSITOMETRIC CHARACTERISTICS OF DEVELOPING-OUT PAPERS.

In this section a detailed description of the characteristics of the various developing-out papers manufactured by the Eastman Kodak Company will be given. This will include typical curves for the various kinds of material and numerical values relating thereto.

Since the results of any sensitometric test depend to a great extent upon the exact exposing and processing conditions used in making the test, it seems desirable to define with considerable care and detail the sensitometric conditions which have been established in these Laboratories for the testing of these developing-out papers.

Sensitometric Conditions.—For the sake of clarity these conditions have been separated into component parts, each of which will be discussed separately.

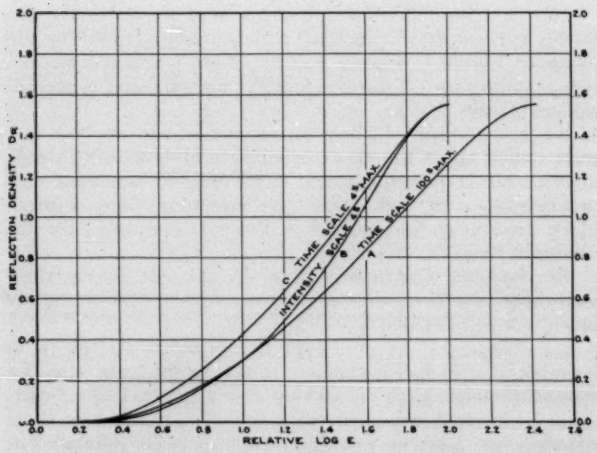
(1) *Exposure.* As stated in the previous section, it is desirable, and in fact necessary, to use an intensity scale for the sensitometric work on developing-out papers if the results are to be in close agreement with the characteristics of these materials as used in practice. As has been pointed out previously (see Fig. 3), practically all developing-out papers exhibit a marked failure of the reciprocity law and hence the shape and position of the characteristic curve depend profoundly upon the time and intensity characteristics of exposure

To illustrate this point further and, in particular, to show the differences between the D-log E characteristics of a material as determined by our present technic and that which was used up until a few years ago, the curves in Fig. 13 are

* Communication No. 737 from the Kodak Research Laboratories.

shown. Curve *A* is based upon a time-scale exposure using an intensity level such that the maximum exposure is 100 seconds. This represents the conditions existing in one of the falling-plate nonintermittent time-scale sensitometers [11] which was used for a number of years in these Laboratories. Curve *B* shows the *D*-log *E* relationship for the same material when exposed on the intensity-scale sensitometer described in the previous section, the illumination being such that a

FIG. 13.



Comparison of time-scale and intensity-scale sensitometric curves for a photographic paper.

satisfactorily exposed strip is obtained when the exposure time, which is constant for all points on the sensitometric strip, is 4 seconds. It will be seen that, on the basis of the older technic, this material appears to have a considerably longer exposure scale than when tested with the intensity-scale technic. Moreover, the time-scale curve shows a much closer approximation to the straight-line relationship in the region of intermediate densities than is shown by the intensity-scale curve *B*. Curve *C* is another time-scale curve

in which the intensity level is adjusted so that the maximum density is obtained with a maximum exposure time of 4 seconds. These curves illustrate very markedly that the shape of the D-log E relationship for this material, even on a time-scale basis, depends profoundly upon the absolute values of exposure time and illumination. Neither of these time-scale curves, however, agrees in shape with the intensity-scale curve made with an exposure time approximating fairly closely that employed in practice.

It is realized that the exposure times used in practice vary over a considerable range. It is quite impossible in the sensitometry of these materials to make the exposure times match perfectly this wide variety of practical conditions. After a consideration of these conditions, we have decided that an exposure time of 4 seconds represents a fair mean and this then has been adopted as standard for practically all of the developing-out papers manufactured by this Company. In one or two cases of extremely fast and extremely slow materials, shorter and longer exposure times are used, respectively.

The increment in log exposure between consecutive steps on the sensitometric strips is in practically all cases 0.10, this being equivalent to a series of exposures, $I \cdot t$, consisting of consecutive powers of $\sqrt[5]{2}$. For the majority of cases, this places the determined points sufficiently close together so that the average curve drawn through the experimental points gives a good picture of the D-log E relationship. In some cases, as will be discussed later, it has been found necessary to decrease this log E increment between the consecutive steps to 0.05 or even to 0.025 in order to establish with sufficient certainty the shape of some parts of the D-log E characteristic.

All exposures are made to the radiation emitted by a calibrated tungsten incandescent filament lamp operating at a color temperature of 2800° K. While this may be somewhat lower than the color temperature of the sources used in practice, it is felt that it is sufficiently close so that no appreciable distortion in the shape of the curve results. It is impossible to operate photometric tungsten incandescent lamp standards at temperatures higher than 2800° K. and obtain at the same

time a satisfactorily long life without troublesome variations in luminous intensity.

The illumination on the sample is adjusted so that with the 4-second exposure the processed strip will show densities from zero to the maximum obtainable with the material, thus giving a complete determination of the entire curve.

TABLE II.

Development and Exposure Conditions.

	Exposure Time	Max. Illumination (m.c.s.) in Sensitometer
(1) D–72, 1 : 2, 45 sec., 70° F.		
Azo	4 sec.	1700
Ad-Type	4	1700
Velox	4	1200
Velox Rapid	4	1200
D.O.P. 22	4	240
Kodabrom	4	70
(2) D–72, 1 : 4, 90 sec., 70° F.		
P.M.C. Bromide	4	70
Eastman News Bromide	4	70
(3) D–52, 1 : 1, 90 sec., 70° F.		
Vitava Athena	8	1700
Vitava Opal	4	240
Kodalure	4	240
Eastman Portrait Proofing	4	70
Vitava Projection	4	70
(4) D–72, 1 : 1, 30 sec., 70° F.		
Line Solar Bromide	4	1200
(5) D–72, 1 : 1, 45 sec., 70° F.		
Insurance Bromide	0.5	70
(6) D–52, 1 : 0, 90 sec., 70° F.		
Eastman Translite Enlarging	4	240
(7) D–85, 1 : 0, 120 sec., 68° F.		
Kodalith	4	70

Since developing-out papers vary considerably in sensitivity, it is therefore necessary to adjust this illumination to fit the classes of paper. Precise specification of the illumination values used will be found in Table II.

(2) *Processing.* Since it is desirable to obtain by sensitometric testing the characteristics of these papers which will

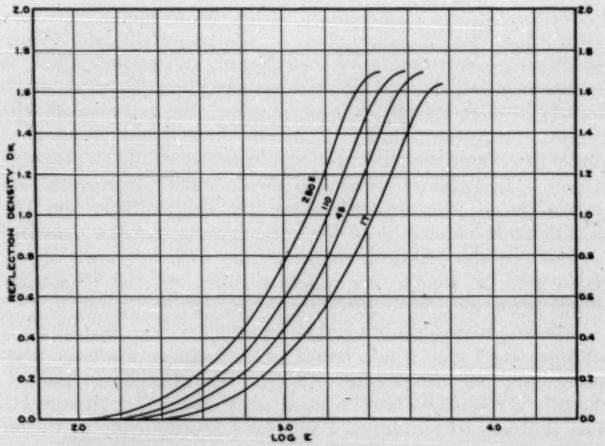
probably most closely represent their characteristics when used in practice, a developing solution, identical in constitution, concentration, temperature, etc., with that used predominantly in practical work, should be selected for the processing of the sensitometric strip. It is, of course, difficult to establish with certainty the average processing conditions existing in practice, but it seems reasonable to assume that the processing recommendations made by the manufacturer should at least result in the most satisfactory performance of these materials. We have therefore adopted for the processing of the exposed sensitometric strips the developer, development time, etc., recommended by the manufacturer. Since developing-out papers vary considerably in characteristics, it has been found that no single developer gives the most satisfactory results for all of these papers. We have taken the position, therefore, that it is unwise to attempt to adopt a single developer for use in the sensitometry of developing-out papers. In Table II are shown the developer, in terms of its code number, the concentration, the temperature, and the development time as used for various groups of the developing-out papers. Also on the same line with the name of the paper will be found the exposure time and the maximum illumination used in making the sensitometric exposures.

When processing, the exposed samples are clipped to a stainless steel rack which is slid to the bottom of a large tray containing the developing solution. During development, the tray is rocked by hand continuously and rather vigorously. The problem of obtaining a precisely reproducible agitation during development is not of as great importance as it is in the case of the sensitometry of negative materials, because developing-out papers are in practice always developed to the point where a stable curve shape has been reached. Developing to an extent greater than this produces no further change in the *shape* of the D-log E relationship, but merely produces a translation of the curve in a direction parallel to the log exposure axis. All kinds of developing-out papers of course do not behave in exactly the same way with regard to the change in shape of the characteristic curve with increasing extent of development. The influence of development time

upon curve shape for several typical groups of materials is illustrated in Figs. 14 to 17, inclusive.

In Fig. 14, curves for the four different development times, as indicated by the attached numbers, are shown for Azo F No. 2. It will be seen that, even with as short a development time as 17 seconds and with the rocked-tray agitation used in the sensitometry of these materials, the curve has attained a shape which is almost identical with that obtained by longer

FIG. 14.



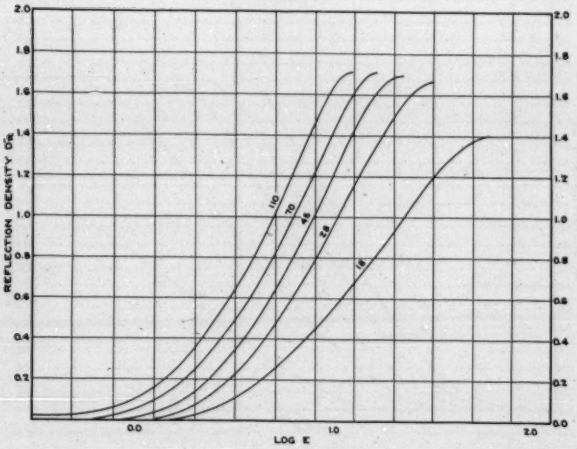
Sensitometric curves for different development times for chloride emulsions of the Azo type.

development times. The maximum density has not quite reached its equilibrium value. However, at 45 seconds, complete equilibrium of shape has been reached and the prolongation of development up to 280 seconds produces no further change in shape. The curve, however, moves continuously to the left, this movement being, in fact, equivalent to a decrease in exposure. While these curves pertain specifically to an Azo paper, the same general behavior of curve shape as a function of development time is found for practically all

of the chloride papers, such as Azo, Ad-Type, Velox, Velox Rapid, etc.

In Fig. 15 is illustrated the way in which the curve shape for a Kodabrom paper changes with development time. It will be seen that development is somewhat less rapid than for the chloride type of papers and that, at 28 seconds, equilibrium of shape has not quite been reached. At 45 seconds, however, equilibrium has been reached and further develop-

FIG. 15.



Sensitometric curves for different development times for chlorobromide emulsions of Kodabrom type.

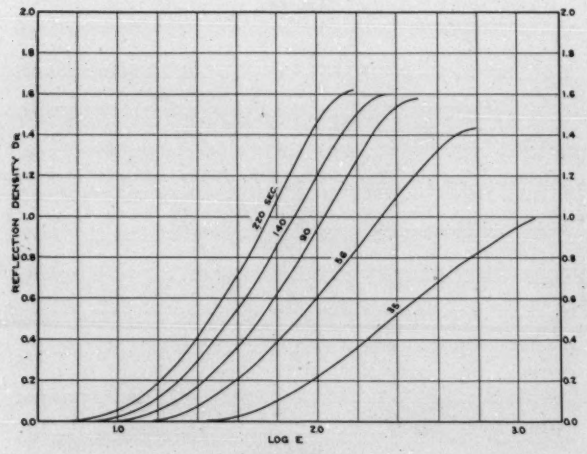
ment produces no further change in curve shape, but merely a bodily shift of the curve towards the left, the direction corresponding to decreasing exposure. The condition illustrated in this figure represents quite generally the behavior of various chlorobromide developing-out papers.

Curves for Vitava Opal *F*, another paper belonging to the chlorobromide group, are shown in Fig. 16. In this case, a development time of 90 seconds is required before equilibrium of shape is reached. Further prolongation of development

time up to 220 seconds gives curves of practically identical shape which shift progressively in the direction of decreasing exposure. The curves in Figs. 15 and 16 are typical of the chlorobromide group to which Kodabrom, Vitava Athena, Vitava Opal, Vitava Projection, and Kodalure belong.

In Fig. 17 are shown curves for P.M.C. Bromide No. 1 normal. Here, again, the rate of development is relatively

FIG. 16.



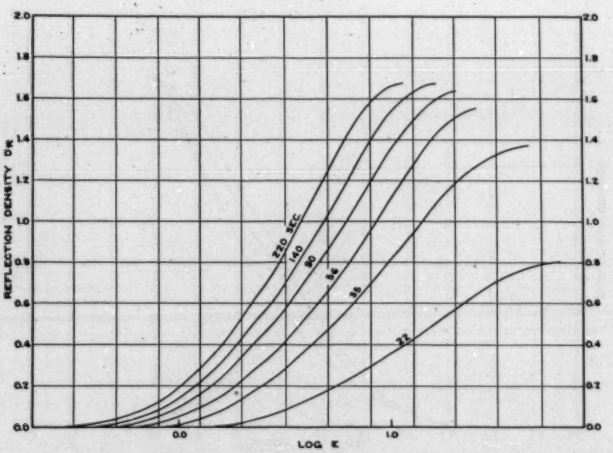
Sensitometric curves for different development times for chlorobromide emulsions of the Vitava Opal type.

low, somewhat lower in fact than for the chlorobromide group. However, 90 seconds' development gives almost complete equilibrium of curve shape and further prolongation of development time results in very little change in shape and a progressive shift in the direction of decreasing exposure.

The behavior of curve shape as a function of development time, as shown in Fig. 17, is typical of the bromide papers which, of course, include the P.M.C. Bromides, Eastman News Bromide, etc. The reader has probably noticed certain

typical differences in the shape of the curves, after they have reached equilibrium for the different types of papers illustrated in Figs. 14 to 17. It may be of interest to compare the shapes of these curves a little more carefully and therefore in Fig. 18 are shown three curves, all of which are for materials having a glossy surface and identical maximum density values. They are also practically identical with respect to *contrast*. Curve *A* is typical of the chloride group, *B* of the

FIG. 17.

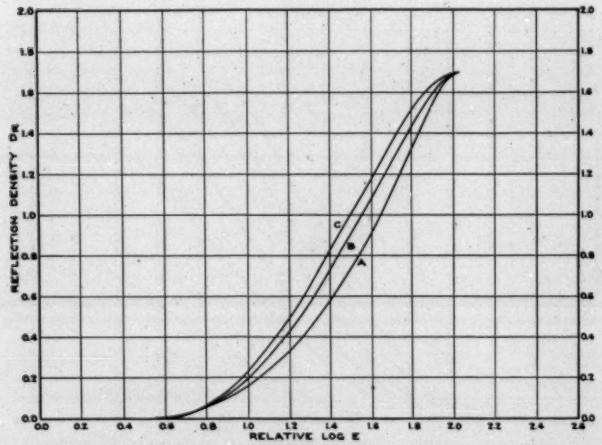


Sensitometric curves for different development times for bromide emulsions of the P.M.C. type.

chlorobromide group, and *C* of the bromide group. It will be noted that a bromide paper tends to give a curve approaching more closely a straight line of appreciable length. The breaking away from the straight line in the shoulder region is somewhat more gradual than in the case of a paper of the chloride type. A chloride paper, shown by curve *A*, shows little if any straight-line region. The portion which approaches most closely a straight-line relationship lies in a region of relatively high densities, approximately 0.8 to 1.5,

or possibly 1.6, for glossy surface chloride papers. The fact that this close approach to linearity between density and log exposure extends so nearly to the maximum density of the material is of considerable significance in tone reproduction problems and determines the shape of the negative characteristic which will give the most perfect objective reproduction of brightness differences in the object. At values of density only a little less than maximum density, the gradient of the

FIG. 18.



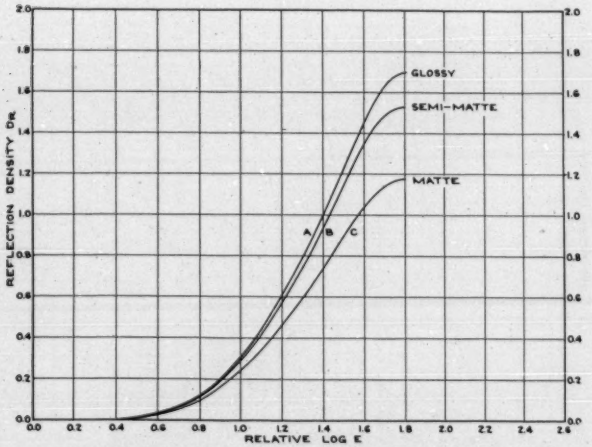
Comparison of bromide, chlorobromide and chloride emulsions of approximately the same contrast.

curve decreases very rapidly, and in a relatively small log exposure range falls to a value of zero. At densities below this approximately straight portion, gradient decreases fairly slowly, thus giving the curve its typical long sweeping toe.

All of the curves thus far used to illustrate typical differences between the kinds of paper relate to very high glossy surface papers. As will be noted, all of these materials have a maximum density which is of the order of 1.70. The maximum density of a developing-out paper depends profoundly

upon the surface finish. The curves in Fig. 19 illustrate this fact. These show the curve shapes obtained when the same emulsion is used to produce papers which have surfaces varying from high gloss to a dull matte, the light from the latter surface being almost completely diffused after reflection and showing a relatively small specular component. Curves *A*, *B*, and *C* relate to papers having glossy, semi-matte, and matte finishes. It will be noted that the maximum density

FIG. 19.

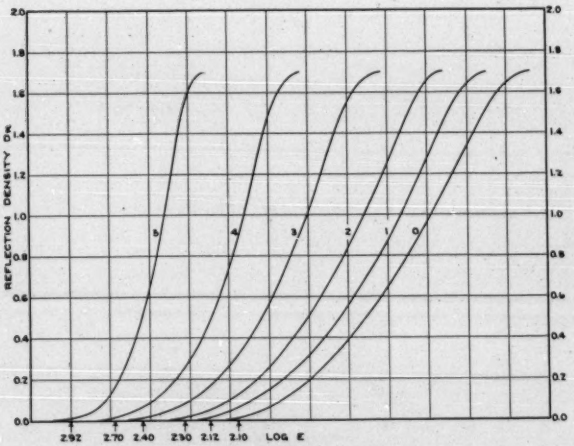


The effect of surface conditions on a photographic paper emulsion.

decreases progressively as the gloss decreases and the surface becomes almost completely diffusing, as in the case of curve *C*. It is interesting also to note that the exposure scales for these three materials are practically identical. Maximum density in each case is obtained at the same exposure value, while the extreme toes extend to the same exposure values. This condition is a general one and applies to practically all developing-out papers, although, of course, there may be some minor deviations.

We shall now consider the characteristic curves of a group of typical developing-out papers. In Fig. 20 are shown the curves for the Azo *F* series of six different "contrast" grades. *Contrast* increases progressively from grade 0 to grade 5. Maximum densities are practically identical for all members of this group. It is seen that these papers show practically no straight-line portion. Beginning at the low-exposure end, the gradient increases rather slowly at first and then more

FIG. 20.



Typical sensitometric curves of Azo papers.

rapidly until the inflection point is reached, after which it decreases first slowly and then very rapidly. In practically all cases there is an appreciable log exposure interval over which the gradient changes but little. However, the strictly straight-line portion, if it exists, is extremely short and comprises such a small proportion of the total scale that it is of little significance from the standpoint either of practice or of tone reproduction theory. It should be noted that in Fig. 20 (as well as in the subsequent Figs. 21 to 25, inclusive), the

TABLE III.

Sensitometric Values for Developing-Out Papers.

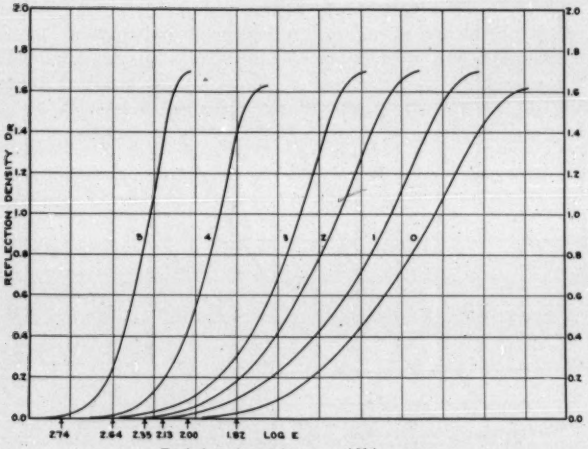
Contrast Grade	*S*	*ES*	Log *ES*	Maximum Density 1.70 Ω	1.70 $G_{max.}$	1.53 Ω	1.53 $G_{max.}$	1.40 Ω	1.40 $G_{max.}$	1.30 Ω	1.30 $G_{max.}$	1.20 Ω	1.20 $G_{max.}$	1.17 Ω	1.17 $G_{max.}$
Vitava Athena															
						A, B, E_{sm} X, Y		*G, L, P, W*		*E_m*				*C, D, E_r, H, Q*	
	25	32	1.50			40	1.40	34	1.25	29	1.20			23	1.10
Axo and Ad-Type															
				C, F, J		*B, E, G, K, L, X, Y*		*AA, P* Ad-Type		*A, D, H, Q*					
0	80	30	1.48	42	1.80	34	1.70	28	1.60						
1	75	26	1.41	50	1.90	40	1.80	34	1.65	29	1.30				
2	50	20	1.30	60	2.45	49	2.10	41	1.90	34	1.70				
3	40	15	1.18	72	3.20	59	2.70	49	2.40	41	2.10				
4	20	9	0.95	87	4.10	70	3.50	59	3.20						
5	12	5	0.70	115	5.30	92	4.50	75	4.00						
Veloz															
				F		*E*									
0	150	30	1.48	42	1.80	34	1.50								
1	100	25	1.40	50	2.30	40	1.90								
2	75	19	1.28	60	3.00	49	2.45								
3	45	13	1.11	72	3.80	59	3.20								
4	23	7	0.85	95	5.00	70	4.00								
5	15	5	0.70	126	6.30	84	5.00								
Veloz Rapid															
				F		*E*									
0	500	26	1.42	46	1.80	37	1.50								
1	300	20	1.30	50	2.30	40	1.90								
2	200	20	1.30	60	3.00	49	2.45								
3	100	12	1.08	72	3.80	59	3.20								
4	65	5	0.70	125	5.00	100	4.00								
Vitava Opal															
				F		*A, B*		*G, L, P, W*		*E_{sm}, Z*		*T*		*C, D, E_r, H, Q*	
	1,300	22	1.34	50	1.85	40	1.75	34	1.60	29	1.45	25	1.35	23	1.30

TABLE III (*Continued*).

Contrast Grade	*S*	*ES*	Log *ES*	Maximum Density 1.70 Ω	1.70 $G_{max.}$	1.53 Ω	1.53 $G_{max.}$	1.40 Ω	1.40 $G_{max.}$	1.30 Ω	1.30 $G_{max.}$	1.20 Ω	1.20 $G_{max.}$	1.17 Ω	1.17 $G_{max.}$
Kodalure															
								G, J, M, P, R, S							
	1,250	23	1.36					38	1.70						
Vitava Projection															
				F		*A, B, E_{sm} X, Y*		*G, L, P, W*		E_m				*C, D, E_r*	
2	3,300	23	1.36	50	1.85	40	1.70	34	1.60	29	1.50			23	1.20
3	2,500	18	1.26	60	2.00	49	1.85	40	1.80	34	1.65			28	1.30
Kodabrom															
				F		*E*		*G, N, P*							
1	11,000	30	1.48	42	1.60	34	1.50	28	1.45						
2	7,800	25	1.40	50	1.80	40	1.70	34	1.65						
3	4,500	13	1.11	60	2.25	49	2.10	41	2.05						
4	3,400	7	0.85	80	3.45	65	3.00	54	2.75						
P.M.C. and News Bromide															
				1, 4, 10 News		2, 9		8, 11, 12				5, 6		3, 7	
n	20,000	30	1.48	36	1.60	28	1.40	24	1.20			18	1.15	16	1.10
m	13,000	16	1.20	55	2.30	45	1.95	38	1.65					25	1.60
c	6,500	11	1.03	70	2.80	58	2.40	48	2.00					32	1.90
x.c.	6,200	9.5	0.98	72	2.95	59	2.50	49	2.10						

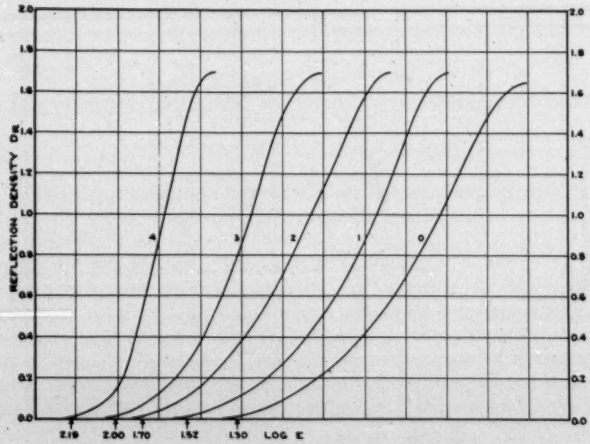
curves for the various contrast grades have been displaced laterally relative to the log exposure axis so that the shapes may be clearly discerned. This avoids the confusion that might arise if they were all plotted to an absolute exposure scale. For information on the relative sensitivities of these materials, reference should be made to Table III in which are given values of speed. This group of curves is typical of all the Azo papers, although those papers with less glossy surfaces show lower maximum densities.

FIG. 21.



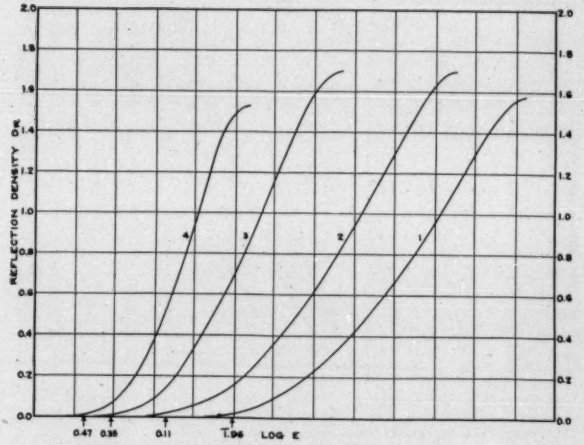
Typical sensitometric curves of Velox papers.

FIG. 22.



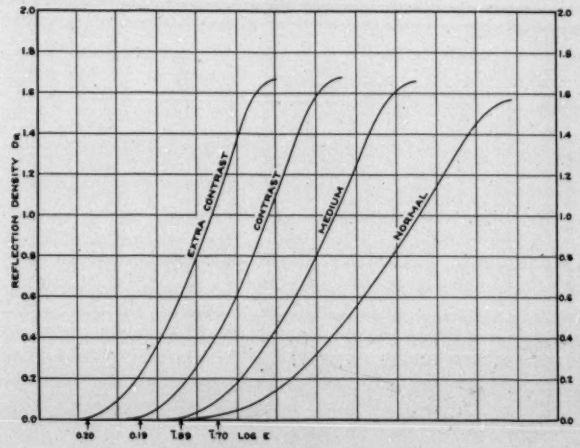
Typical sensitometric curves of Velox Rapid.

FIG. 23.



Typical sensitometric curves of Kodabrom.

FIG. 24.

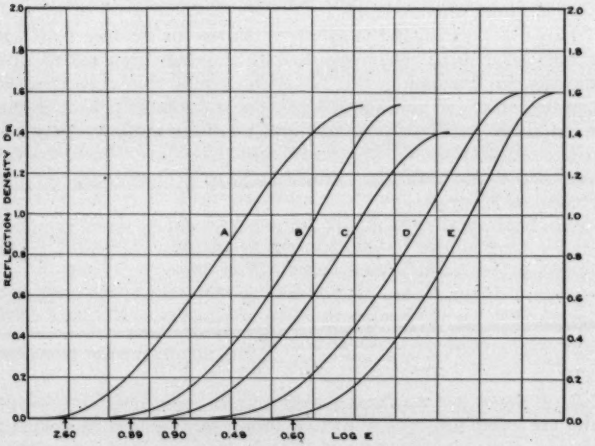


Typical sensitometric curves of P.M.C.

In Fig. 21 is shown a similar group of curves applying to the Velox *F* series in six grades of contrast. They are very similar in shape to those of the Azo curves shown in Fig. 20. The existence of a straight-line portion of any appreciable length is doubtful.

In Fig. 22 is shown a similar set of curves for the five contrast grades of Velox Rapid *F*.

FIG. 25.



Typical sensitometric curves of miscellaneous papers.

The three groups of curves in Figs. 20 to 22 are representative of the chloride papers and we wish to call attention again to the fact that for all of these papers, beginning with low exposure values, the gradient, that is the slope, of the *D*-log *E* curve increases rather gradually as exposure is increased, reaching a fairly high value which persists for an appreciable log exposure range and then decreases quite suddenly to zero at maximum density. These characteristics are of considerable importance from the standpoint of the tone reproduction which can be obtained when using these papers and have a

very important bearing upon the characteristics of a negative which most perfectly "fits" the printing material.

In Fig. 23 is shown a group of curves for the four contrast grades of Kodabrom *F*. As has been mentioned before, this is a paper of the chlorobromide type. In the region of intermediate densities, the *D*-log *E* curve approaches more closely to a straight-line relationship, but even in this material the straight-line region, if it exists, covers a very small log exposure range. The *shoulders* are rather sharply curved and the *toes* long and sweeping.

In Fig. 24 is shown a group of curves for the four contrast grades of P.M.C. Bromide No. 1. As has been noted previously in discussing the bromide group, they give curves tending more to show a straight-line relationship with somewhat more gradual shoulders and less long and sweeping toe regions than the chlorobromides and chlorides. These curves are also typical of the other bromide groups, such as the Eastman News Bromides.

In Fig. 25 are given curves for a few other papers, namely:

A Vitava Athena *B*
B Vitava Opal *B*
C Kodalure *M*
D Vitava Projection *B* No. 2.
E Vitava Projection *B* No. 3.

All of these are of the chlorobromide type and have curve shapes which are typical of that group represented by curve *B* in Fig. 18.

(*To be concluded in December issue.*)

ARTIFICIAL RADIOACTIVE INDICATORS.

BY

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(*Concluded from October issue.*)

Reactions Involving Manganese.—Polissar (45) has tested the following oxidation-reduction reactions:

$MnO_4^- + \dot{M}n^{++}$	no exchange
$MnO_4^- + \dot{M}n(C_2O_4)_2^-$	no exchange
$Mn^{++} + \dot{M}n(C_2O_4)_2^-$	complete and rapid exchange
$MnO_4^- + \dot{M}nO_2$	no exchange
$Mn^{++} + \dot{M}nO_2$	no exchange

In all cases an excess of inactive component was present initially, and separation of components was realized by filtration of MnO_2, after addition of alkali when required. An active filtrate would constitute evidence of exchange.

Of special interest is the equilibrium between the permanganate and manganous ions which, according to Launing and Yost, is established with great rapidity. The constituents were maintained in a $\frac{10\ MnO_4^-}{1\ \dot{M}n^{++}}$ ratio in solutions of varying acidity for as long as fifteen minutes, after which the manganous ion was precipitated as MnO_2 and the activity of filtrate and precipitate examined. In the event that complete exchange occurred, most (91 per cent.) of the activity should remain in the filtrate as $\dot{M}nO_4^-$. As it happened, all of the activity was recovered in the precipitate showing that the interaction between MnO_4^- and Mn^{++} must be exceedingly slow if it occurred at all.

Reactions Involving Sulfur.—Preceding discussions have emphasized the facility with which exchanges between like atoms can be determined directly by means of radioactive isotopes. Another type of study which is possible when radioactive indicators are available is illustrated by some experiments of E. B. Anderson (46) involving the nature of

the sulfur atom linkages in sodium thiosulfate. Anderson showed by the following series of reactions that the sulfur atoms in thiosulfate were not chemically equivalent.

$$\overset{*}{S} + Na_2SO_3 = Na_2\overset{*}{S}\,SO_3$$

$$2AgNO_3 + Na_2\overset{*}{S}\,SO_3 = NaNO_3 + Ag_2\overset{*}{S}\,SO_3$$

$$Ag_2\overset{*}{S}\,SO_3 + H_2O \xrightarrow{\text{b.p.}} H_2SO_4 + Ag_2\overset{*}{S}$$

Radioactive thiosulfate was prepared from radioactive sulfur and sodium thiosulfate. To test the equivalence of the sulfur atoms, it was necessary only to remove part of the sulfur and determine the fraction of the total activity which is removed with it. This separation was effected by adding silver nitrate to precipitate silver thiosulfate, and then heating the suspension to boiling in order to hydrolyze the insoluble silver salt into silver sulfide and sulfuric acid. Equivalence of the sulfur atoms would demand that the active sulfur be found distributed equally between the precipitated sulfide and the sulfate ions in solution. As a point of fact, the solution was entirely inactive whereas the Ag_2S contained all of the original activity. Hence it follows directly that the original central sulfur atom in $SO_3^=$ and the coordinated sulfur atom are not equivalent. Substantially the same conclusion may be drawn from the direct acidification of the radioactive sodium thiosulfate. Practically all of the activity is recovered in the precipitated sulfur, with but a trace carried away as sulfur dioxide.

In contrast with the above example, Voge and Libby (47) reported evidence for the equivalence of the sulfur atoms in ammonium polysulfide. Active sulfur was dissolved in an excess of ammonium sulfide at 100°, and the polysulfide solution acidified to yield sulfur and hydrogen sulfide, both of which were converted into solids suitable for measurement of activity. Complete exchange resulted, giving the impression that added sulfur atoms in the polysulfide are indistinguishable from the central sulfur atom. Furthermore, Voge and Libby have studied a number of reactions involving inorganic sulfur compounds in aqueous alkaline media. The following table (IX) reviews their findings.

TABLE IX.

Sulfur Exchanges in Alkaline Medium.

Reactants.	Time.	Result.
$S^{=} + \overset{*}{S}O_4^{=}$	36 hrs.	No reaction at 100°
$SO_3^{=} + \overset{*}{S}O_4^{=}$	36 hrs.	No reaction at 100°
$\overset{*}{S}^{=} + S_2O_3^{=}$	2 hrs.	No reaction at 100°
$\overset{*}{S}^{=} + S_2O_3^{=}$	1 day	Considerable reaction

No reaction took place, in oxygen-free alkaline solutions, between sulfate ions and sulfide from sodium sulfide even after thirty-six hours at 100° C. The same was true of a mixture of sulfate and sulfite under similar conditions. An exchange of sulfur between sulfide and thiosulfate ions did occur, but only at 100° and required more than two hours before becoming evident.

Reactions Involving Arsenic and Phosphorus.—Wilson and Dickinson (48) have measured the velocity of opposing reactions at equilibrium, by means of active arsenic, in the oxidation of arsenious acid by iodine. Incidental to this study, which is to be considered later in greater detail, they examined mixtures of arsenate and radioactive arsenite ions for possible exchange in the absence of iodide ions or free iodine. Boiling for three hours in normal acid or alkali solutions failed to transform any of the active arsenic to the arsenate form, as was immediately evident when the arsenate, precipitated as magnesium ammonium arsenate and converted to the pyrophosphate, proved to be devoid of activity. Summing, we may say:

$$\overset{*}{A}sO_3^{=} + AsO_4^{=} \rightarrow \text{no reaction.}$$

A similar negative result was obtained by Wilson (49) for the phosphate-phosphite exchange in acid or alkaline solutions even after a week at 100°. Hence

$$\overset{*}{P}O_4^{=} + PO_3^{=} \rightarrow \text{negligible reaction.}$$

Indicator Applications of Radioactive Gold. (*a*) *Self-diffusion.*—Diffusion of atoms of a given element through the bulk of the same material can be studied only if distinguishable

isotopes are available. Thus the auto-diffusion of lead (50) has been followed by means of thorium B as radioactive indicator for lead. Radioactive gold has now permitted the measurement of the diffusion coefficient of gold atoms in massive gold as well as the temperature coefficient of the diffusion process. Radioactive gold, obtained by neutron bombardment of a gold foil, was covered with a layer of inactive gold, and the diffusion of active atoms into the inactive material allowed to proceed at high temperatures. The distribution of activity, and hence the diffusion coefficient, was found by dissolving successive layers of gold in a nitric-hydrochloric acid mixture and determining the quantity of active gold present in each portion. Sagrubsky (51), who performed these experiments, reports the following coefficients (D) of diffusion:

t° C.	D cm.²/day.
800.....	1.3×10^{-7}
850.....	5.0×10^{-7}
1000.....	1.5×10^{-4}

These data do not satisfy strictly the exponential equation $D = Ae^{-Q/RT}$, although between 800 and 850°, the activation energy (Q) of the diffusion process is about 63,000 calories/mole and the constant A is about 8×10^5 cm.²/day.

(*b*) *Analytical Application.*—Erbacher and Philipp (52) have used active gold to indicate the completeness with which gold can be separated from platinum and iridium by a gravimetric procedure in which the components are weighed after reduction to the metallic state. Starting with an aqua regia solution of known composition, component elements were precipitated as metals by reduction with sodium formate at an elevated temperature after first making the solution alkaline with potassium hydroxide. The precipitated metals were washed and ignited, then digested with aqua regia to redissolve gold and platinum; the iridium, being insoluble upon ignition, remained behind and was weighed after filtration. Gold was separated from platinum by reduction with hydrogen peroxide, after making the medium alkaline, successive portions of peroxide being added until no more precipitate appeared. After filtration of the gold for weighing and elimination of excess peroxide, metallic platinum was precipi-

tated by reduction with sodium formate. Again the addition of reducing agent was continued until all precipitation was complete.

The analytical results showed that the iridium recovered was always 4–10 per cent. higher than that present initially, the conclusion being that digestion of the ignited metals in aqua regia did not remove gold or platinum quantitatively, although which predominated could not be stated. Similar findings with the gold fraction seemed to show that hydrogen peroxide reduced some platinum salt along with the gold. Examination of the three metal fractions with a Geiger-Muller counter readily yielded additional information concerning the effectiveness of the separation. Most unexpected was the observation that although the weight of gold fraction precipitated by hydrogen peroxide usually exceeded the original weight of the element, the actual gold content, as shown by radioactive measurements, was less. In other words the platinum content was greater even than was indicated by the gravimetric analysis. For example, a platinum-gold mixture containing 0.4323 g. of gold yielded 0.4678 g. of metallic deposit upon addition of peroxide, which might be interpreted as a simultaneous precipitation of 0.0355 g. of platinum with the 0.4323 g. of gold. Radioactive measurements showed, however, that this reduced gold contained only 97 per cent. of the total gold and that, therefore, the platinum contamination consisted of 11 per cent. instead of only 8 per cent. of the gold fraction. The remaining 3 per cent. of activity was recovered in the platinum obtained by addition of formate. Evidently the peroxide is not too effective as a gold precipitant; and in one of the experiments reported by Erbacher and Philipp, even five successive additions of this reducing agent failed to lead to a quantitative separation, this in spite of the fact that more than half of the platinum salt had been reduced to metallic platinum along with the gold. Always appreciable amounts—1.5 to 10.8 per cent.—of gold (as shown by its activity) remained to be precipitated with platinum upon addition of sodium formate. When iridium was present, the iridium fraction usually was active, which signified incomplete extraction of gold by the strong acid digestion.

Mechanism of Organic Reactions. (*a*) *Inversion Reactions.*—Radioelements have contributed to the better understanding of the mechanism of a number of organic reactions, among them being the so-called Walden inversion and the Hoffmann rearrangement. It has been demonstrated how conveniently radioactive isotopes lend themselves to the investigation of reactions of the type $RX + X^-$ where X is a halogen atom and R is some organic radical. When this residue contains an asymmetric carbon atom, it has been observed that inversion occurs under the influence of halogen ions. Many investigations have led to the conclusion (53) that the inversion of organic halides is due to a substitution of the halogen ion for the halogen in the organic compound; and that when the inversion reaction is reversible as in the case of substitution by like atoms, the ultimate result will be formation of a racemic product.

That inversion, or racemization, really is due to the replacement of halogen in the organic molecule is the inescapable conclusion to be drawn from the work of Hughes, Juliusburger, Masterman, Topley and Weiss. These investigators have measured the velocity of racemization of d-sec octyl iodide (10) by sodium iodide, as well as the velocity of exchange of iodide ion for iodine in the sec-octyl iodide under identical conditions. The reactions in question were carried out in acetone, and may be written:

$$(a) \quad \text{d-RI} + \text{NaI} = \text{r-RI} + \text{NaI}$$

$$(b) \quad \text{RI} + \text{Na}\overset{*}{\text{I}} = \text{R}\overset{*}{\text{I}} + \text{NaI}.$$

The course of the former reaction was followed by means of the change in rotatory power as measured with a polarimeter. The extent of exchange was determined by extracting the sodium iodide and examining its activity. The decrease in active iodide is a measure of the exchange which had occurred.

It follows of necessity that, if the substitution and racemization are interdependent, they must proceed with the same velocity. This is precisely what was found in acetone at 30° C. as is seen from Table X. The average of five exchange experiments yields an absolute reaction rate of 3.00×10^{-5} moles/l./sec.; whereas for racemization the rate

TABLE X.

Rate of Substitution Reaction.	Rate of Stereochemical Inversion.
3.04×10^{-5}	2.88×10^{-5}
3.15×10^{-5}	2.86×10^{-5}
2.43×10^{-5}	2.89×10^{-5}
3.06×10^{-5}	
3.32×10^{-5}	
Av. $3.00 \times 10^{-5} \pm 0.25$	Av. $2.88 \times 10^{-5} \pm 0.03$

is 2.88×10^{-5} moles/l./sec. In all cases the observed rates have been reduced to a common basis as regards concentration of reactants. The concordance is satisfactory considering the experimental error of the radioactive measurement and shows clearly the mutual relationship between optical inversion and exchange.

The same conclusion was arrived at from analogous experiments (54) performed in acetone solutions with d-α-phenylethyl bromide and lithium bromide, since again the rates of exchange and racemization were equal.

Recently Long (32) investigated a possible exchange of oxalate ions between potassium chromioxalate and potassium oxalate prepared from radioactive carbon under conditions favorable to the racemization of the complex. The fact that no exchange was observed indicated that the reaction was not ionic.

(*b*) *Rearrangement of N-Chloroacetanilide.*—N-chloroacetanilide rearranges to p-chloroacetanilide by a mechanism usually thought of as involving the intermediate formation of chlorine. An intramolecular reaction also has been suggested as a possible explanation. In order to determine the extent to which the latter alternative was justified Olson, Porter, Long and Halford (56) studied the reaction in the presence of radioactive hydrochloric acid. The chlorine intermediate hypothesis assumes chlorination of acetanilide as the final step in the formation of the p-chloroacetanilide. Since equilibrium between chlorine and chloride ion is attained even before the chlorination of acetanilide can begin, this mechanism, if valid, would require that the chlorinated product be highly radioactive. On the other hand, exclusive intramolecular rearrangement would obviate the formation of

active p-chloroacetanilide; and the disappearance of active chloride ion from solution should be regulated solely by exchange with the N-chlorine atom of the unrearranged chloramine. Thus the test resolves itself into an attempt to reproduce the measured rate of disappearance of radioactive chloride ion from solution by introducing observed velocity constants in kinetic expressions appropriate for the various possible mechanisms.

Necessary data were obtained with an aqueous acid (1 N H_2SO_4) solution which was 0.04 M with respect to both N-chloroacetanilide and $Na\overset{*}{C}l$. The rate of rearrangement was measured iodimetrically and yielded a satisfactory unimolecular rate constant (k_1). The velocity with which active chlorine was removed in the course of the reaction was found directly from the residual activity of the solution. The rate constant for exchange of Cl^- with the N-chlorine atom was obtained by determining the amount of active chlorine in the unrearranged chloramine after the reaction had gone about 25 per cent. to completion. Examination of the chlorinated product indicated a high degree of activity. This information together with the knowledge that the Cl_2-Cl^- exchange is practically instantaneous permitted a decision as to the probable mechanism or mechanisms operating.

The very fact that the chlorine atom in the p-chloroacetanilide is radioactive eliminates intramolecular rearrangement as the sole mechanism. Not even an exchange of the N-chlorine atom simultaneous with the intramolecular change could account for the extensive removal of active chloride from solution, for this exchange is too slow. And neither did the "chlorine intermediate" assumption appear to be satisfactory by itself since it predicted a rate of removal of chloride ion much greater than was observed. To account for the measured decrease in activity of solution, Olson, Porter, Long and Halford (56) were forced to conclude that both mechanisms were operative, 43 per cent. of the rearrangement proceeding intramolecularly and 57 per cent. by way of chlorine.

In a later paper Olson, Halford and Horvel (57) eliminated the intramolecular explanation entirely. More extended

analysis of the system showed that the chloride ion concentration of the solution did not remain constant during the reaction, but increased gradually due to some unidentified reaction of the chloramine. The presence of additional chloride ion obviously diminishes the speed with which radioactive chlorine can be removed, hence renders the chlorine path more plausible since the removal of $\overset{*}{Cl}^-$ by this means need no longer be so rapid. Calculations corrected for this additional chloride ion actually show that the experimental values of residual activity as a function of time satisfy the curve predicted by the "chlorine intermediate" mechanism. Thus a direct rearrangement involving no external agencies appears definitely to be excluded.

Reaction Velocity at Equilibrium.—Wilson and Dickinson (48) have demonstrated that the velocity constants of opposing reactions in a reversible reaction at equilibrium are the same as when measured under conditions far from equilibrium. Chemical methods do not permit velocity observations of opposed processes at equilibrium, although it is generally accepted that, could such measurements be performed, the forward and back rate constants would be identical with the constants determined under nonequilibrium conditions. This expectation was supported by a study of the oxidation of arsenious acid by iodine, in solutions containing equilibrium quantities of all components. Complete kinetic and equilibrium relationships are available for the reaction

$$H_3AsO_3 + I_3^- + H_2O \rightleftarrows H_3AsO_4 + 3I^- + 2H^+,$$

which permitted computation of equilibrium concentrations of components.

Metallic arsenic was activated by neutron bombardment, then burned to form arsenious oxide, which was dissolved in normal alkali and diluted as desired to form solutions containing a known concentration of $\overset{*}{AsO_3}^{\equiv}$ ion. Stock reaction mixtures were obtained by adding known amounts of hydrochloric acid and inactive arsenic acid solutions. Blanks gave no evidence of exchange in such mixtures. Reaction was induced by addition of standard potassium iodide solution,

and the whole maintained in a thermostat for 4½ to 17 hours. The amount of iodide added was such that comparatively little free iodine (≤ 1 per cent. of added iodide ion) was present, so as to insure but slight reaction at non-equilibrium conditions. Hence any transfer in activity from trivalent to pentavalent arsenic could be attributed to the operation of the reversible reaction at equilibrium. At the conclusion of a given time interval, the reaction was stopped by diluting with water, and the distribution of As between arsenite and arsenate was determined by precipitating $AsO_4^{\equiv}$ as the magnesium ammonium salt, igniting to the pyroarsenate, and comparing the activity of a known weight of this solid with that of a similarly prepared standard, using a quartz fiber electroscope. The velocity of the opposing oxidation-reduction reactions was calculated in terms of concentrations of tri- and pentavalent arsenic and of the distribution of radioactive arsenic between these two forms of arsenic. The velocity constants calculated from the rates of exchange of valence between the $AsO_3^{\equiv}$ and $AsO_4^{\equiv}$ at equilibrium at 25° and 35° was found to agree with the constants reported in the literature for conditions far removed from equilibrium. Furthermore the temperature coefficient of the exchange reaction was in accord with the value derived from the direct chemical measurements. Evidently the velocity constants at equilibrium are the same as under non-equilibrium conditions.

Botanical Studies.—Certain obvious advantages are gained by employing radioelements in investigating the transport and deposition of elements in living organisms. Because of the ionizing properties of radioactive radiations, the distribution of an "indicated" or "labelled" element is readily revealed simply by observing the effect of various tissue sections on an electroscope or counter; and because of the sensitivity of this means of detection, it is possible to examine pathological substances without fear of harm to tissue. These advantages had been recognized by von Hevesy in 1923 when he used thorium B (lead) to trace the absorption and distribution of lead in plants and animals (59).

Most researches dealing with the storage and elimination of elements in plants and animals are restricted to measure-

V.2
193

ments of net concentration changes occurring in various parts of the plant or animal. Thus, except in extreme cases, it is difficult to distinguish between material newly deposited or synthesized and that present initially. In this connection isotopes in general, and especially the radioactive isotopes because of their ease of detection, are extremely valuable since, by virtue of exchange with an inactive isotope, they demonstrate or disprove the occurrence of dynamic processes within the organism. Obviously such phenomena as surface exchange, deposition, or turnover of mineral matter may be distinguished.

The first report of a successful application of an artificial radioelement in the field of botany was presented by Hevesy, Linderstrom-Lang and Olsen (60) who demonstrated a continual replacement of phosphorus atoms during the development of maize plants. These workers grew small maize plants for ten days in a phosphorus (as sodium phosphate) containing culture, and then transferred them to another nutrient solution of the same composition except for the presence of radioactive phosphorus, where they remained until after a new growth of leaves appeared. At various times after immersion in the radioactive solution, the leaves and the stem were ashed and analyzed chemically for total phosphorus, and for radioactive phosphorus by means of a counter. The following table (XI) gives the ratio of the weights of indicated or labelled phosphorus to the total phosphorus present in a particular ash. Measurements were made at about four, seven, fourteen and twenty-one days after the change of nutritive solution. The second set of leaves appeared after the fourteen days observation.

The amount of "indicated" phosphorus was obtained from the activity of the ash and the activity and total phosphorus content of the second nutrient solution. Thus if a given fraction of the original activity is present in a leaf, then the same fraction of the original total phosphorus in the solution also is involved. Ostensibly this calculation is based on the chemical inseparability of isotopes. However, there are certain tacit assumptions inherent in the calculation when applied to complicated systems, namely, that the indicated phosphate neither exchanges with nor is diluted by inactive

phosphorus compounds from other sources, and that the labelled phosphorus is not utilized in the synthesis of other compounds.

Now if phosphorus is permanently incorporated in the stem, then the inactive phosphorus taken up during immersion in the first solution should not take part in the further growth of the plant as evidenced by appearance of leaves. In other words the phosphorus content of the new leaves should

TABLE XI.

Migration of Phosphorus in Plants.

Plant.	Time of Experiment (days).	Part of Plant.	$\frac{\text{"Indicated" P}_{(mg.)}}{\text{Total P}_{(mg.)}}$.
Maize	3.8	Stem	0.395
		Leaves	0.318
	7.0	Stem	0.630
		Leaves	0.445
	13.8	Stem	0.733
		Leaves	0.672
	21.0	Stem	0.791
		1st leaves	0.709
		2nd leaves	0.698
Sunflower	4	Stem	0.637
		Lower leaves	0.436
		Upper leaves	0.515
	9	Stem	0.856
		Lower leaves	0.669
		Upper leaves	0.656

originate not in the stem but in the second nutritive solution, and therefore the active phosphorus should be concentrated in the new leaves. On the other hand, if a dynamic equilibrium exists between phosphorus atoms in different parts of the plant, then some of the phosphorus involved in the growth of the stem should be found in the leaves whereas simultaneously active phosphorus should appear in the stem. Furthermore, in the limiting case of complete distribution, the ratio of labelled phosphorus to ordinary phosphorus should be the same in all parts of the plant. Obviously the absolute value of the ratio is immaterial since it depends upon the initial

phosphorus content of the plant and the amount of phosphorus which has been absorbed by the plant from the nutrient solution.

That the supposition regarding a continual movement is valid is attested to by the accompanying table (XI), especially by the last set of measurements performed after the appearance of a new set of leaves. It is evident that the exchange of phosphorus between the older and the new leaves was practically complete, since both sets show almost identical ratios of active to inactive phosphorus. Even the ratio in the stem differs only by about 12 per cent. from that in the leaves, which points to an extreme mobility of phosphorus containing compounds, and that migration of phosphorus between different parts of the plant occurred continuously. A similar conclusion can be drawn for the first three sets of observations, involving stages in the plant development prior to the formation of the second set of leaves, namely the growth of earlier leaves. Here too, considerable interchange had occurred, the ratios for stem and leaves deviating only by some 10 per cent. after 13.8 days. That the stem is always somewhat richer in activity than higher portions of the plant is not unexpected in view of its favored position with respect to the active solution.

Reference has already been made to the assumptions underlying the calculation of labelled phosphorus. Whenever the calculation is valid, the ratio of the labelled phosphorus to the uptake (increase in quantity) of total phosphorus is unity, and the radioelement acts as a "tracer" for the behavior of phosphorus. Should exchange occur simultaneously with deposition, however, the ratio of labelled phosphorus to the total phosphorus increase in the plant would exceed unity since exchange involves only a replacement of the active by inactive phosphorus initially present. As regards removal of phosphorus by synthesis of new compounds, the ratio would be unaltered because active and inactive element would participate equally. Evidently the radioactive indicator can be more than just a tracer of the path of an element; it can supply information concerning the nature of the changes taking place. Clearly a knowledge of the increase in total phosphorus, localized or for the whole organism, adds to the "tracer" type of observation an indication as to whether and

where exchange occurs; and isolation of radioactive compounds indicates synthesis of these compounds which could not have been ascertained by ordinary means if a stationary concentration of the particular compound was being maintained. Thus the radioelement can be used to measure the deposition and turnover of its normal isotope in various tissues.

In the experiments with corn plants, the absorption of phosphorus from solution is not known, so that we measure a ratio of labelled phosphorus to initial plus absorbed phosphorus. This ratio increases with time because of the continued uptake of phosphorus from the solution. However there is no indication as to whether any exchange occurs in the plant since we do not know its initial phosphorus content; and we can conclude only that the phosphorus is free to move in the plant.

Similar migration phenomena appear to occur as well during the growth of the sunflower plant (61). Applying the same technique as for the maize plants, Hevesy, Linderstrom-Lang and Olsen grew a "lower" set of leaves in an inactive phosphate solution and then an "upper" set of leaves in an active solution. Again total phosphorus was determined chemically and indicated phosphorus from the activity of the ash, and the ratio obtained. The results show that here also the phosphorus is in a mobile state and fairly free to migrate between stem and leaves.

Incidental to the latter investigation, the possibility of direct exchange between sunflower leaves and a nutrient solution was ruled out. Leaves from a plant grown in a radioactive nutritive solution were kept in an ordinary solution for 48 hours and the activity of the solution examined. No active phosphorus could be detected in solution, showing that no interchange had occurred. Experiment with inactive cut leaves immersed in an active solution showed a small uptake of active phosphorus due probably to direct absorption of active solution.

Measurements of the uptake of phosphate by germinated maize and pea seeds also are included in this research.

No exchange of phosphorus occurred in yeast (62) grown for several days in a given culture and then immersed in a similar culture containing several milligrams of indicated

phosphorus. After growing for a day in the active culture, the yeast was removed and analyzed for total and indicated phosphorus. This information, together with the initial phosphorus content of the yeast plant determined before exposure to the radioactive nutritive solution, revealed the uptake of total and labelled phosphorus. The ratio was found to be unity, so that the yeast cells either contained chiefly non-exchangeable organic phosphorus compounds, or were actually impermeable to phosphate.

Gustafson and Darken (13) have used active phosphorus to demonstrate the upward transport of phosphate in the phloem of geranium plant stems. Apparently the accepted path was through the woody part or xylem, and migration through the phloem surrounding this portion was undemonstrated and even doubted. These investigators immersed stems, from which most of the xylem had been removed, into an active dihydrogen phosphate culture solution, and then tested the activity of the sheath of bark as a function of distance above the level of remaining xylem. In spite of the absence of the woody tissue, presumably necessary for mineral conduction, active phosphorus was detected at heights of ten and more centimeters above the point where the xylem had been removed; and beyond this point, only phloem was available for conduction. A second set of experiments compared two geranium stem cuttings, one being intact with xylem and serving as a control for the second from which the xylem had been removed. In both stems the vertical distribution of phosphorus was similar. This again points to the phloem of stems as a path by which minerals may be transported upwards in plants.

Phosphorus Metabolism. (*a*) *Absorption, Distribution and Excretion.*—When phosphorus is fed to animals in the form of phosphate, part is absorbed and the remainder is eliminated more or less rapidly in the excreta after passing unaffected through the gastro-intestinal tract. Of the phosphate which is retained, part will be deposited directly in a given tissue, perhaps to be transferred to other tissues, and some will be utilized in biological syntheses. The absorbed phosphorus will be eliminated gradually, eventually finding its way into the urine and feces. The use of a distinguishable isotope

allows the direct determination of the various deposition sites even though ordinary phosphorus is present initially; and the isotope can be used to demonstrate biological syntheses, and their locale, in which the given element participated. Frequently it is possible to show that migration occurs from tissue to tissue, as was illustrated by certain of the botanical applications.

The first paper dealing with the metabolism of radioactive phosphorus was that of Chievitz and Hevesy (63) who fed radioactive sodium phosphate to rats and then determined the distribution of active phosphorus in the body as well as the rate at which it was eliminated. After twenty-two days, almost 60 per cent. of the radioactive phosphorus had been excreted; and of the remainder, more than half was found in the bone structure and about 40 per cent. in the muscles and fat of the animal. Actually, however, after taking into account the relative weights of the various organs examined, the activity per unit weight of tissue was found to be greatest in the brain, spleen, kidney and liver. Practically all of the active phosphorus was eventually eliminated in the feces and excreta; and from the rate of excretion of activity it was estimated that the average life of a phosphorus atom in a normal adult rat is about two months. From this it would appear that a continuous turnover of phosphorus occurred; and since most of the phosphorus is absorbed in the bone tissue the latter must be the seat of this replacement process.

This investigation revealed further (64) that the specific activity (active phosphorus per unit weight) of the bone ash of growing rats was many times greater than that of normal adult rats, which is understandable on the basis of bone growth from blood of high active phosphorus content. However, a comparison of growing rats of different ages discloses also that the phosphorus is being rapidly eliminated from the bone structure, some being excreted, some being utilized in biological syntheses, and still another portion migrating to other parts of the body. A similar turnover appears to take place in the teeth (64, 88). Attempts (64, 65) to distinguish an effect of administration of vitamins A and D on the phosphorus uptake by rachitic rats as compared with normal rats have as yet been inconclusive or negative.

Excretion experiments based on oral administration do not permit of a differentiation between phosphorus eliminated after absorption and that which passes unabsorbed through the digestive tract. Hahn, Hevesy and Lundsgaard (66) avoid this complication by injecting active phosphate directly into the blood stream of a rabbit. Again excreta were collected periodically, and after twenty-seven days the animal was killed and the distribution of active and total phosphorus determined. The elimination vs. time curve is approximately logarithmic, and the time required for the elimination of half the administered activity was about twenty days, so that the average life of a phosphorus atom in the rabbit is about one month. Of course the time which a phosphorus atom spends in the animal's body depends on the extent of exchange with ordinary phosphorus in the body, the bulk of which is found in the bone structure. It turns out, however, that the ratio of active to inactive phosphorus in the bone tissue was much smaller than in the other organs examined, and smaller than the average for the entire body. One must conclude therefore that the exchange which determines the measured life time is considerably restricted, and that, were the phosphorus content of the bones not protected against exchange, the average life would be even greater than one month. Further study suggested that the slow process may be due to the imperfect penetration of the bones by the blood stream. There was also some indication, from the similarity in $\frac{\dot{P}}{P_{total}}$ ratios for the liver, blood, kidneys and muscles, that a fairly free transfer of phosphorus took place between these organs, although this agreement may have been accidental.

Scott and Cook (67) suggest that the preponderant deposition of radioactive phosphorus in bones makes possible a means of irradiating regions of the body, such as bone marrow, not readily accessible to ordinary X-ray treatment. These authors were able to establish changes in the blood picture of white leghorn chicks, although undoubtedly the quantities of $\dot{P}$ which they employed exceeded the amount needed for an indicator experiment.

Phosphorus deposition in growing white leghorn chicks was investigated by Cook, Scott and Abelson (68). The birds were fed active phosphate, and then killed for analysis either four or sixty days after the administration of the phosphorus. Again it was found that most of the activity collected in the bones and muscle; but a comparison of the analyses after four days and after sixty days showed a marked decrease in activity of all organs other than the bone to the advantage of the latter, which showed a striking increase in radio-phosphorus content during the growth of the chicks. The process of growth appears also to make for a more uniform $\frac{\dot{P}}{P}$ ratio throughout the body, which would be expected on the basis of a transfer of phosphorus atoms. A higher ratio in the brain and in the bone marrow could be attributed to the synthesis of radioactive phospholipid.

Cohen and Greenberg (69) noted that in the preceding investigations analyses were performed a long time after administration which might have permitted the establishment of an approximately steady state with respect to radioactive phosphorus. Hence they proceeded to investigate the absorption, distribution and excretion of phosphorus by rats immediately after ingestion or injection of the radioactive indicator as disodium phosphate. Absorption experiments showed that active phosphorus passed through the stomach in about eight hours, and that only about four hours were required for the unretained active phosphorus to pass into the urine and the large intestine. Excretion experiments likewise indicate that unretained phosphorus is eliminated within 4–8 hours. Distribution measurements confirmed the extensive deposition of $\dot{P}$ in the bones and muscles. Curves of $\dot{P}$ content vs. time showed a maximum after several hours, due probably to the simultaneous accumulation and elimination of phosphorus in the different tissues. The high concentration of activity in the liver has been shown (vide infra) to be due to newly synthesized phospholipid.

(*b*) *Biological Syntheses; Phospholipid Metabolism.*—Proof of the synthesis of phospholipids directly from phosphate injected into young rats has been presented by Artom,

Sarzana, Perrier, Santangelo and Segré (70). After being injected with $Na_3\overset{*}{P}O_4$ daily for four days, the animal was bled and the tissues extracted with hot alcohol and alcohol plus ether to recover lipidic compounds, the phosphorus content of which was determined analytically. From the extracted tissue residues, non-lipidic constituents were removed by means of cold trichloroacetic acid and separated into acid-soluble and acid-insoluble (taken to consist chiefly of nucleo-proteins) portions, both of which were analyzed for phosphorus. The radioactivity of all fractions was measured and the results expressed as specific activities of the various tissues (no data reported for the acid-soluble portion). The lipidic phosphorus removed from the kidneys, liver and intestines possessed the highest specific activity, the lowest being found in the muscle, brain and medulla. The specific activity of acid-insoluble phosphorus also was highest in the liver and intestine and lowest in the nervous tissue. It can hardly be denied that the liver, intestine and kidneys play an active part in the metabolism of both phosphatides and nucleo-proteins, and that both types of phosphorus-containing substances are synthesized in the body directly from inorganic phosphorus.

The same authors (71) studied the influence of feeding a fatty substance such as olive oil along with the active sodium phosphate. The rat was bled nine hours after ingestion of $\overset{*}{P}$ and the lipidic fraction extracted from the different tissues and analyzed for active and total phosphorus. Substantially the same distribution was obtained as in the absence of fat absorption: liver, intestine and kidneys, where most of the active phosphatide was located, showed high specific activities, the intestine having the highest value. These experiments indicate that, although substitution of fatty acid radicals in the phosphatide molecules may occur in the organs mentioned, a complete synthesis of the phospholipid molecule proceeds simultaneously. Furthermore, since only nine hours elapsed between administration and analysis, the synthesis in the presence of ingested fat must be rather rapid.

Hevesy and Lundsgaard (72) believe that the rapid formation of phospholipids in these organs when fat is

included in the diet accounts for the increased lecithin content of the blood of dogs soon after consumption of a meal containing fat. They arrived at this conclusion by administering fat and active phosphate simultaneously and then analyzing the blood lecithin for active and total phosphorus. If the effect of the fat is to mobilize lecithin already formed at the time of administration of the active phosphorus then the additional lecithin should be completely inactive; if the lecithin is synthesized in the intestinal tract before resorption into the blood stream, then practically all of the phosphorus of the additional lecithin should be radioactive; however, should the synthesis take place in some organ, as the liver, outside the intestinal tract, only part of blood lecithin increase would involve active phosphorus, and therefore only a small portion of the absorbed $\dot{P}$ should be found in the blood stream. The latter supposition appeared to be the most reasonable because, of the total amount of active phosphorus absorbed by the dog, only 4.6 per cent. was present in the blood stream after six hours.

The formation of radioactive lecithin in the brain of rats, rabbits, and mice was investigated quantitatively by Hahn and Hevesy (73) with a view to testing the assumption that no regeneration of tissue occurred in brain of adult animals. Thus $\dot{P}O_4^{\equiv}$ was administered to a series of fully grown rats, which were killed after one hour, three days and five days. Examination of the brain and its lecithin content demonstrated that the lecithin was radioactive, and that activity of this lecithin increased with time. The synthesis of active lecithin in the brain is proof that in the brain phospholipid is not immobilized, and that the lecithin in the brain tissue of adult rats is constantly being regenerated. Tests of a possible exchange of phosphorus between $\dot{P}O_4^{\equiv}$ and rat brain tissue (all inorganic phosphorus carefully removed) "in vitro" yielded a small positive result probably due to enzymatic action.

Similar experiments with other isolated (excised) tissues of the rats have been reported by Robinson, Perlman, Ruben and Chaikoff (74) who find that active phospholipid synthesis,

stimulated by glucose, occurred "in vitro" in the liver, kidney and intestine.

The early stages in the phospholipid metabolism have been studied in considerable detail by Perlman, Ruben and Chaikoff (75) who administered $Na_2H\overset{*}{P}O_4$ to fasting rats, either with or without cod liver oil, and determined the distribution of radioactive phosphatide in the liver, gastrointestinal tract, etc. as a function of time for about four days. All tissues examined were found to contain active phospholipid, the amounts in the liver, kidneys and intestinal tract passing through a maximum in less than a day. The ingested fat appeared to increase the rate of active phospholipid formation as well as the maximum amount formed. The most rapid formation was observed in the liver and intestinal tract as shown by the height and position of the maximum. The turnover was slow in the remainder of the animal since even after 100 hours a maximum had not yet been attained. The rate curves suggest a return to a steady state after several days, the time probably required for uniform distribution of the newly synthesized (active) phospholipid.

In these experiments, the stomach, the small and the large intestine had been grouped together as the gastrointestinal tract. Subsequent investigations (76) showed that of these organs only the small intestine was the locale of a rapid turnover of phospholipid.

A high content of active phosphatide in a given organ is not necessarily proof that the phospholipid is actually synthesized in this organ since the possibility of transfer from organ to organ remains. That such transfer between the intestinal tract and the liver cannot account for the presence of active lipid in the latter organ was shown (76) by repeating the distribution experiments with animals deprived of their gastrointestinal tract and their kidneys. The time variation of active phosphatide in the liver was about the same as that observed with normal rats, so that the synthesis in the liver is independent of similar processes occurring in other organs.

An extension (77) of these indicator studies to the phospholipid metabolism in laying and non-laying white leghorn chickens has been reported.

Absorption of Sodium.—The rate of absorption of sodium into the blood stream from the digestive tract was followed by giving human subjects an $\dot{N}aCl$ solution to drink and noting the number of impulses registered by a small counter held in the hand of the subject. A state of sodium balance in the body was established before observations were begun. In this manner Hamilton (78) found that in many subjects a constant activity was registered after some three hours although in some subjects the sodium absorption measured in this way continued to rise gradually even after ten hours. In these measurements, the sodium activity was not revealed by its proper radiation but by the γ-radiation emitted by the magnesium atoms resulting from the disintegration of the radioactive sodium.

No detrimental effects of $\dot{N}a$ have been observed. Absorption and excretion data have been published by Hamilton and Stone (79).

Absorption of Potassium.—The absorption of radioactive potassium by normal adult rats (80) is about 90 per cent. complete within a half hour and is retained chiefly by muscles and other soft tissue. Elimination is mostly through the kidneys.

Brooks (81) has studied the entrance of active potassium (as chloride) into living nitella clavata cells from solutions of different pH. After $8\frac{1}{2}$, 10 and 20 hours, cells were removed and the sap and protoplasm squeezed out, leaving the cell walls. These three components were placed on glass slides and their activities per unit weight determined. This study indicates that the $\dot{K}$ deposits first in the protoplasm, from which slow diffusion into the sap occurs.

Bale and Haven (82) mention the use of radioactive iron, iodine and sulfur as biological indicators though published details are not yet available to the writers. Borsook, Keighley, Yost and McMillan (83) have fed active sodium sulfate to human subjects previously maintained on a constant sulfur diet (hence constant sulfur content in the urine), and then examined the urine for active and inactive sulfur. From their observation that the ratio $\left(\frac{\text{labelled } S}{S \text{ increase}}\right)$ in the urine

was about 0.6 they concluded that exchange of sulfate ion had occurred in body tissues.

Active iodine has been employed by Hertz, Roberts and Evans (84) to demonstrate selective concentration of iodine in the thyroid gland of rabbits. Thyroid stimulation increased the uptake of radioactive iodine by this gland. Of twelve other tissues and body fluids examined, only the blood (into which the indicator was injected) and urine contained significant activities.

ADDENDUM.

Some twenty papers which have appeared in the interval between preparation and publication of this review will be mentioned briefly in the following paragraphs.

Active phosphorus has been used to measure the solubility of ammonium phosphomolybdate (85) in nitric acid and molybdic acid solutions. The principle of this method is presented in references (1) and (2). Redetermining the activation energy of gold self-diffusion, McKay (86) found a value of 51,000 calories per mole. For the self-diffusion of copper, Rollin (87) reported an activation energy of 60,000 calories.

Distribution and metabolism studies by means of active phosphorus are among these recent contributions. Thus it has been demonstrated that in leg bones of rachitic chickens (89), the active phosphorus content is greater and the total phosphorus content is less than in normal birds. With a view towards elucidating the mechanism of phospholipid metabolism, perfusion and other experiments with isolated cat and rabbit livers have been performed (90). Studies of phospholipid metabolism in rats have shown, for example, that ingestion of choline enhances the phospholipid turnover in the liver of fat-fed rats (91). The source of phosphatides in egg yolks (92), the diffusion of phosphate ion into blood corpuscles (93), the mechanism of enzymatic phosphorylations, as in alcoholic fermentation (94), and numerous other problems (95) have been investigated with active phosphorus as indicator. The enzymatic processes mentioned above constitute a new method of preparing complicated organic compounds containing active phosphorus "in vivo" and "in vitro."

Two of the recent reports involve the absorption of active sodium, potassium, and the halogens in the form of salts by living subjects. In rabbits (96) injected (intravenously) with Na^{24}, a constant blood activity was realized in less than one-half hour. These measurements permitted an estimate of the volume of extracellular body fluids. As regards human subjects (97), the absorption of potassium proceeds more slowly than that of sodium and the halogens, requiring five hours for completion instead of three hours.

REFERENCES.

1. PANETH AND VON HEVESY: *Z. anorg. Chem.*, **82**, 323 (1913).
2a. PANETH: "Radio-Elements as Indicators." McGraw-Hill, N. Y., 1928.
2b. O. HAHN: "Applied Radiochemistry." Cornell University Press, Ithaca, N. Y., 1936.
3. GUÉBEN: Ann. Soc. Sci. Bruxelles, **57** [1], 238 (1937).
4. LAWRENCE AND LIVINGSTON: *Phys. Rev.*, **40**, 19 (1932); Lawrence and Cooksey: *Phys. Rev.*, **50**, 1131 (1936).
5. GEIGER AND MÜLLER: *Phys. Z.*, **29**, 839 (1928); **30**, 489 (1929).
6. WYNN-WILLIAMS: *Reports on Progress in Physics*, **3**, 239 (1937).
7. FAY AND PANETH: *J. Chem. Soc.*, **1936**, 384. (See ref. 9 for circuit.)
8. LAURITSEN AND LAURITSEN: *Rev. Sci. Instruments*, **8**, 438 (1937).
9. HAMBLIN AND JOHNSON: *Phil. Mag.*, **24** [7], 553 (1937). (Give the most elementary exposition.)
10. HUGHES, JULIUSBURGER, MASTERMAN, TOPLEY AND WEISS: *J. Chem. Soc.*, **1935**, 1525.
11. OLSON, LIBBY, LONG AND HALFORD: *J. Am. Chem. Soc.*, **58**, 1313 (1936).
12. BREJNEVA, ROGINSKY AND SCHILINSKY: *Acta Physicochemica* (*U. R. S. S.*), **5**, 549 (1936).
13. GUSTAFSON AND DARKEN: *Science*, **85**, 482 (1937).
14. For review see ref. 2b, Chaps. II and IV.
15. GROVEN, GOVAERTS AND GUÉBEN, *Nature*, **141**, 916 (1938); HOFFMAN AND BACHER: *Phys. Rev.*, **54**, 644 (1938).
16. FERMI, AMALDI, D'AGOSTINO, RASETTI AND SEGRÉ: *Proc. Roy. Soc.*, **146A**, 483 (1934).
17. AMALDI, D'AGOSTINO, FERMI, PONTECORVO, RASETTI, AND SEGRÉ: *Proc. Roy. Soc.*, **149A**, 522 (1935).
18. PANETH AND FAY: *Nature*, **135**, 820 (1935).
19. GOVAERTS: *Nature*, **141**, 871 (1938).
20. HAISSINSKY: *Nature*, **136**, 141 (1935).
21. STEIGMAN: *Phys. Rev.*, **53**, 771 (1938).
22. LIVINGOOD AND SEABORG: *Phys. Rev.*, **50**, 435 (1936).
23. SZILARD AND CHALMERS: *Nature*, **134**, 462 (1934).
24. BRASCH, LANGE, WALY, BANKS, CHALMERS, SZILARD AND HAPWOOD: *Naturwiss.*, **22**, 839 (1934).

25. ROGINSKY AND GOPSTEIN: *Phys. Z. Sowjetunion*, **7**, 672 (1935).
26. MAJER: *Naturwiss.*, **25**, 252 (1937).
27. ERBACHER AND PHILIPP: *Z. physikal. Chem.*, **176A**, 169 (1936).
28. ERBACHER AND PHILIPP: *Ber.*, **69**, 893 (1936).
29. PANETH AND ROSENBLUM: *Nature*, **139**, 796 (1937).
30. RASETTI: *Z. Physik*, **97**, 64 (1935).
31. GLÜCKAUF AND FAY: *J. Chem. Soc.*, **1936**, 390.
32. LONG: Abstract of Papers, Div. Phys. Inorg. Chem., Am. Chem. Soc., Milwaukee, Sept. 1938, p. 28.
33. PANETH: *Ber.*, **51**, 1704 (1918).
34. VON HEVESY AND ZECHMEISTER: *Ber.*, **53**, 410 (1920).
35. ZIRKLER: *Z. Physik*, **87**, 410 (1934).
36. Reviewed by ROSENBLUM: *Revue des Questions scientifiques*, **30** [4], 23 (1936).
37. VON GROSSE AND AGRUSS: *J. Am. Chem. Soc.*, **57**, 591 (1935).
38. TOPLEY AND WEISS: *J. Chem. Soc.*, **1936**, 912.
39. JULIUSBURGER, TOPLEY AND WEISS: *J. Chem. Phys.*, **3**, 437 (1935).
40. HULL, SHIFLETT AND LIND: *J. Am. Chem. Soc.*, **58**, 535 (1936).
41. LONG AND OLSON: *J. Am. Chem. Soc.*, **58**, 2214 (1936).
42. MCKAY: *Nature*, **139**, 283 (1937).
43. HULL, SHIFLETT AND LIND: *J. Am. Chem. Soc.*, **58**, 1822 (1936).
44. KOLTHOFF AND YUTZY: *J. Am. Chem. Soc.*, **59**, 1634 (1937).
45. POLISSAR: *J. Am. Chem. Soc.*, **58**, 1372 (1936).
46. ANDERSON: *Z. physik. Chem.*, **32B**, 237 (1936).
47. VOGE AND LIBBY: *J. Am. Chem. Soc.*, **59**, 2474 (1937).
48. WILSON AND DICKINSON: *J. Am. Chem. Soc.*, **59**, 1358 (1937).
49. WILSON: *J. Am. Chem. Soc.*, **60**, 2697 (1938).
50. VON HEVESY AND OBRUTSHEVA: *Nature*, **115**, 674 (1925).
51. SAGRUBSKY: *Phys. Z. Sowjetunion*, **12**, 118 (1937).
52. ERBACHER AND PHILIPP: *Angrew. Chemie*, **48**, 409 (1935).
53. OLSON AND LONG: *J. Am. Chem. Soc.*, **56**, 1294 (1934).
54. HUGHES, JULIUSBURGER, SCOTT, TOPLEY AND WEISS: *J. Chem. Soc.*, **1936**, 1173.
55. FOWLER AND DODSON: Abstracts of Papers, Div. Phys. Inorg. Chem., Am. Chem. Soc., Milwaukee, Sept. 1938, p. 9.
56. OLSON, PORTER, LONG AND HALFORD: *J. Am. Chem. Soc.*, **58**, 2467 (1936).
57. OLSON, HALFORD AND HORVEL: *J. Am. Chem. Soc.*, **59**, 1613 (1937).
58. BREJNEVA, ROGINSKY AND SCHILINSKY: *Acta Physicochemica* (*U. R. S. S.*), **7**, 201 (1937).
59. For review, see ref. 2a, pp. 87–89, and VON HEVESY: *Z. Elektrochem.*, **38**, 504 (1932).
60. HEVESY, LINDERSTROM-LANG AND OLSEN: *Nature*, **137**, 66 (1936).
61. HEVESY, LINDERSTROM-LANG AND OLSEN: *Nature*, **139**, 149 (1937).
62. HEVESY, LINDERSTROM-LANG AND NIELSEN: *Nature*, **140**, 725 (1937).
63. CHIEVITZ AND HEVESY: *Nature*, **136**, 754 (1935).
64. CHIEVITZ AND HEVESY: *Kgl. Danske Videnskab. Selskab, Biol. Medd.*, **13**, No. 9 (1937).
65. DOLS, JANSEN, SIZOO AND DE VRIES: *Nature*, **139**, 1068 (1937).

66. HAHN, HEVESY AND LUNDSGAARD: *Biochem. J.*, **31**, 1705 (1937).
67. SCOTT AND COOK: *Proc. Nat. Acad. Sciences*, **23**, 265 (1937).
68. COOK, SCOTT AND ABELSON: *Proc. Nat. Acad. Sciences*, **23**, 528 (1937).
69. COHEN AND GREENBERG: *J. Biol. Chem.*, **123**, 185 (1938).
70. ARTOM, SARZANA, PERRIER, SANTANGELO AND SEGRÉ: *Nature*, **139**, 836 (1937).
71. ARTOM, SARZANA, PERRIER, SANTANGELO AND SEGRÉ: *Nature*, **139**, 1105 (1937).
72. HEVESY AND LUNDSGAARD: *Nature*, **140**, 275 (1936).
73. HAHN AND HEVESY: *Skand. Archiv. Physiol.*, **73**, 148 (1937).
74. ROBINSON, PERLMAN, RUBEN AND CHAIKOFF: *Nature*, **141**, 119 (1938).
75. PERLMAN, RUBEN AND CHAIKOFF: *J. Biol. Chem.*, **122**, 169 (1937).
76. FRIES, RUBEN, PERLMAN AND CHAIKOFF: *J. Biol. Chem.*, **123**, 587 (1938).
77. ENTENMAN, RUBEN, PERLMAN, LORENZ AND CHAIKOFF: *J. Biol. Chem.*, **124**, 795 (1938).
78. HAMILTON: *Proc. Nat. Acad. Sciences*, **23**, 521 (1937).
79. HAMILTON AND STONE: *Radiology*, **28**, 178 (1937); *C. A.*, **31**, 2677 (1936).
80. GREENBERG, JOSEPH, COHEN AND TUFTS: *Science*, **87**, 438 (1938).
81. BROOKS: *J. Cellular Comp. Physiol.*, **11**, 247 (1938).
82. BALE AND HAVEN: Abstracts of Papers, Div. Phys. Inorg. Chem., Am. Chem. Soc., Milwaukee, Sept. 1938, p. 8.
83. BORSOOK, KEIGHLEY, YOST AND MCMILLAN: *Science*, **86**, 525 (1937).
84. HERTZ, ROBERTS AND EVANS: *Proc. Soc. Exp. Biol. Med.*, **38**, 510 (1938).
85. FERLA: Annali Chim. Appl., **28**, 331 (1938); *Brit. Chem. Abstracts*, 637 (1938).
86. MCKAY: *Trans. Faraday Soc.*, **34**, 845 (1938).
87. ROLLIN: *Phys. Rev.*, **55**, 231 (1939). See also STEIGMAN, SHOCKLEY AND NIX: *Bull. Am. Phys. Soc.*, **13**, 21 (1938).
88. HEVESY, HOLST AND KROGH: *Kgl. Danske Videnskab. Selskab, Biol. Medd.*, **13**, 13 (1937).
89. DOLS, JANSEN, SIZOO AND VAN DER MAAS: *Nature*, **142**, 953 (1938).
90. LUNDSGAARD: *Skand. Arch. Physiol.*, **80**, 291 (1938); C. A., **33**, 713 (1939). HAHN AND HEVESY: *Biochem. J.*, **32**, 342 (1938).
91. CHANGUS, CHAIKOFF AND RUBEN: *J. Biol. Chem.*, **126**, 493 (1938). PERLMAN AND CHAIKOFF: *J. Biol. Chem.*, **127**, 211 (1939).
92. HEVESY AND HAHN: Proc. Copenhagen Acad., **14**, 2 (1938). See HEVESY: *Nuovo Cimento*, **15**, 279 (1938).
93. ATEN AND HEVESY: *Nature*, **142**, 871 (1938).
94. PARNAS: *Enzymologia*, **5**, 166 (1938). MEYERHOF, OHLMEYER, GENTNER AND MAIER-LEIBNITZ: *Biochem. Z.*, **298**, 396 (1938).
95. HEVESY AND REBBE: *Nature*, **141**, 1097 (1938). HEVESY: *Enzymologia*, **5**, 166 (1938). See review by HEVESY: *Nuovo Cimento*, **15**, 279 (1938).
96. GRIFFITHS AND MAEGRAITH: *Nature*, **143**, 159 (1939).
97. HAMILTON: *Am. J. Physiol.*, **124**, 667 (1938).

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

FIRE EXTINGUISHMENT WITH CARBON DIOXIDE.

Tests with carbon dioxide as an extinguishing medium for fires in building contents were recently conducted in Washington under the auspices of the Federal Fire Council in a building due to be razed on the site of the proposed building for the Social Security Board. A report of these tests including also results of three tests previously conducted in a building at the National Bureau of Standards will soon be released. The main object of the tests was to determine the extent to which fire extinguishment with carbon dioxide is feasible as applied by a fire brigade responding to an alarm. It is apparent that a large part of the damage inevitably caused by water could thus be avoided, which is important where valuable contents are involved.

The gas was released from the liquid state at a temperature in the tank near 0° F. in the case of the recent tests, and at ordinary atmospheric temperatures in the previous tests. At the lower temperature the pressure in the container is less than one-third of what obtains for temperatures near 70° F. and the volume for a given weight is also less. This makes it possible to use lighter containers, although necessitating refrigeration. If discharged from the liquid state at initial temperature within the range indicated above with no loss or addition of heat, from 50 to 70 per cent. is released as gas and the rest as snow or ice. However, due to rapid absorption of heat by the fine particles, under most conditions only a minor amount of the solid is left after a few minutes.

The extinguishment is effected by replacing in part the oxygen of the air with inert gas. Thus, fires in alcohol, gasoline and kerosene will be extinguished if the oxygen content of the air is reduced from the normal 21 per cent. to 15 per cent. To extinguish fire in wood, paper, cotton and

* Communicated by the Director.

similar materials after it has progressed for some time requires a proportionately greater amount of the gas to reduce the oxygen content of the air to the range 8 to 10 per cent. This concentration of the gas must be maintained for some time to enable it to penetrate into the burning mass and to allow for cooling to temperatures at which reignition will not take place.

Some tests were designed to simulate prompt application of the gas by automatic means actuated by automatic fire detectors or similar devices. Others simulated delayed application of the gas such as would obtain where the fire must be discovered and an alarm sent to a public or private fire brigade which would apply the gas with portable or motor driven equipments. It was found in tests made with prompt application of the gas that a much smaller concentration was needed than for delayed application. Thus, in the case of a fire burning vigorously in wood and paper, where the gas was discharged within 4 minutes after the start of a fire, complete extinguishment was effected by the gas in amount equal to 1 lb. per 17 cu. ft. of room volume. This corresponds to a carbon dioxide concentration of about 40 per cent. and an oxygen concentration of about 12 1/2 per cent. Where similar fires were allowed to progress from 12 to 15 minutes, gas concentrations in the range 55 to 65 per cent. were needed to effect complete extinguishment. This corresponds to an oxygen concentration of 9 1/2 to 7 1/2 per cent. Where the fires were allowed to burn for 45 minutes to 1 hour, although all flaming and visible glow could be extinguished with such gas concentrations, the glow farther from the surface had to be extinguished with additional applications of the gas or with relatively small quantities of water.

The tests were conducted within rooms having floor areas from 200 to 5,000 sq. ft. and having volumes in the range 3,000 to 87,000 cu. ft. It was found that the size of the room had little effect on the proportionate amounts of extinguishing medium required. The governing condition appeared to be the amount applied per unit of room volume which would determine the resulting carbon dioxide and oxygen concentrations.

Up to 5,500 lb. of gas was applied in a single test. No difficulty was experienced in obstruction of the gas outlets due to ice formation, this condition having been overcome with the equipment and methods employed.

UNITED STATES ANTARCTIC EXPEDITION.

The United States Antarctic Expedition, which is scheduled to leave early in November, has need for many special kinds of devices and scientific apparatus to secure the information which is desired. The various Governmental agencies have been requested to coöperate with the members of the Expedition to insure the accomplishment of the objectives. Because of the unusual conditions under which the scientific work must be done, special apparatus had to be designed for much of this work.

The National Bureau of Standards is supplying the equipment and apparatus for determining the temperature and density of the snow and ice at various depths. It is planned to install thermometers in the snow at the surface and at various depths down to 160 feet, to determine not only the temperature at the various depths but also how these temperatures are influenced by the air temperatures during the different seasons. In addition, measurements will be carried out at different stations to determine the influence of the local topography on the sub-surface temperatures.

This Bureau is supplying 42 electrical resistance thermometers and 2 wheatstone bridges with the accessories such as switches, extra galvanometers, etc. The instruments will be graduated from + 10° to −70° C. (+ 50° to −94° F.). The thermometers will be located in holes about 2 inches in diameter. Specially designed drills for making the holes are being constructed in the Bureau's instrument shops. Electrical heating devices are also being provided to melt holes into the snow or ice, in case it is not possible to drill the holes to the full depth with the limited man power available.

Apparatus for determining the density of, and communicating air spaces in the snow and ice consist of the following: Balances; sampling devices for obtaining representative samples of snow; triethylbenzene to be used for filling the

communicating air spaces in the density samples; and a number of density standards for determining the density of the various liquids, such as triethylbenzene, kerosene, etc., which will be used in determining the density of the snow.

Because it is difficult to estimate the accuracy which will be obtained with the apparatus at the extreme temperatures at which it will be used, numerous standards, such as resistance coils, freezing point samples, masses, etc., are being provided for the purpose of testing and calibrating the apparatus under the conditions encountered in the Antarctic.

ROLE OF HYDRAULIC LABORATORIES IN GEOPHYSICAL RESEARCH.

In connection with the meetings of the International Union of Geodesy and Geophysics in Washington during the first two weeks of September, a round-table discussion on the subject, "The Role of Hydraulic Laboratories in Geophysical Research," was held at the Bureau on the afternoon of September 13. The International Associations of Hydrology, Meteorology, and Oceanography participated.

Papers and discussions were presented on the following subjects: density currents; wind waves on water; ocean waves; roll waves in steep channels; tides and seiches; flood waves; velocity distribution in open channels; infiltration and run-off; ground water; permeability and specific yield; wind erosion; soil erosion; stream and valley erosion and deposition; silting of reservoirs; formation of sand ripples by water; transportation of bed load by streams; transportation of suspended load by streams; settling velocities and orientation of particles; shore line processes; meteorological phenomena; and instruments and methods of measurement. The papers presented will be published by the Association Internationale d'Hydrologie Scientifique. A few preprints of these papers are available for distribution.

ELECTROPHORETIC STUDIES OF WOOL.

The confusion concerning the location of the isoelectric point of wool, and its significance in wool processing, has arisen from the assumption that the isoionic and isoelectric

points are the same. Wool is in its isoelectric state when the sum of the positive and negative charges at its surface over a time average is equal to zero. On the other hand, the isoionic point is the point at which the acid and basic groups of wool combine equally and only with hydroxyl or hydrogen ions. These two points may be far apart.

By means of the electrophoretic technique, which provides an excellent tool for studying the electrical state of protein surfaces, the isoelectric point of the surface of cortical cells and scales of wool was found to be 4.5. The results of this work are described in an article by Arnold M. Sookne and Milton Harris in the October *Journal of Research* (RP1245). When the fibers were ground, a value of 4.2 was obtained. Whether this lower value has resulted from the degradation of the wool in grinding or is the value for the intracellular material cannot be stated at this time.

The practical significance of the isoelectric and isoionic points is discussed. The former is related to processes such as scouring, finishing and dyeing with colloidal dyes, whereas the latter is related to dyeing with soluble dyes, felting, removal of ash constituents, and to the wet tensile strength of the fibers.

CALIBRATION OF LARGE TESTING MACHINE.

Recently the Bureau was requested by the Baldwin-Southwark Corporation to coöperate in the calibration of a large hydraulic testing machine having a capacity of one million pounds in tension and three million pounds in compression. Because this machine in the research laboratories of the Aluminum Company of America will be used not only for determining the strength and other properties of large specimens and metal structures, but for investigating the rolling and extruding of metals, the movable head may be operated at very unusual speeds of 3 ft. per min. under a load of three million pounds and 12 ft. per min. under no load.

The calibration of a testing machine under loads greater than one million pounds is very unusual, therefore this Bureau was glad to coöperate in this calibration and provided additional proving rings which made it possible to calibrate this machine up to 1,800,000 pounds.

All of the proving rings had been calibrated under dead weights and certified by this Bureau. This activity of the Bureau makes it practicable for the manufacturers of large testing machines to calibrate their machines for the entire range of loads up to a million pounds or more and greatly increases the confidence of the user in the accuracy of the readings.

For loads greater than one million pounds, eight proving rings were used. The errors in the load readings were much less than the guaranteed accuracy, 3/4 of one per cent.

An Amsler box having a capacity of two million pounds will be used to calibrate this machine periodically after it is installed in the research laboratory. For loads greater than 300,000 pounds it is more convenient to use an Amsler box than to use proving rings. Therefore the testing machine was also calibrated using the box. Comparison of the results with proving rings and the box showed that the errors were practically the same, therefore, it was concluded that the Amsler box was satisfactory for the periodic calibrations. The members of the Bureau staff obtained much valuable information on the calibration of large testing machines.

RADIUM EXPOSURE METER DESIGNED AS PROTECTIVE DEVICE.

In hospitals and other institutions where large quantities of radium are handled it is important to protect the technicians from exposure to the radiation of the radium.

There are two general types of overexposure to be guarded against. One is local which occurs when a radium preparation is brought very close to some part of the body for a brief interval. The result of this type of overexposure is a "burn" which is very difficult to heal. It rarely occurs unknowingly since it can be experienced only when actually handling the radium. It can be prevented therefore, by proper regulations and equipment to make it unnecessary to bring any part of the body near the radium.

The second type is a general exposure of the whole body to relatively weak radiation such as occurs to persons in a room having a vault containing radium when an insufficient thickness of lead is used to line the vault. This type of ex-

posure is more insidious than the first type since it may affect persons not actually handling the radium.

Where large amounts of radium are being handled constantly exposures change and, therefore, in the absence of any warning device unsafe conditions may arise without the knowledge of those affected.

The device described in this paper, designed by L. F. Curtiss of the staff, is an apparatus incorporating a Geiger-Müller counter which shows the actual exposure at any moment in terms of roentgens per day.

In addition, when this exposure approaches the amount regarded as the safe limit, it sounds a warning to notify technicians of the danger. With a sufficient number of these units installed in a hospital it would be difficult for any technician to suffer a general overexposure without his knowledge.

A description of this device is published in the *Journal of Research* for October (RP1246).

CONTINUOUS BROADCAST OF STANDARD OF MUSICAL PITCH INAUGURATED.

The Bureau has just inaugurated the continuous broadcasting, throughout day and night, over its radio station WWV, Beltsville, Maryland, of the standard for musical pitch, 440 cycles per second, for A above middle C. This is broadcast continuously as a modulation frequency on a radio carrier frequency of 5 megacycles per second, except during the short periods of other Bureau broadcasts on the same radio carrier frequency.

The station call letters (WWV) are given every ten minutes on the even ten minutes both by voice and by telegraphic keying, so that persons using the service may be sure they are listening to the right station. The radiated power is one kilowatt, with 100 per cent. modulation. The accuracy of the 440-cycle standard pitch (and also of the 5,000-kc. carrier frequency) as transmitted, is better than a part in 10,000,000, which is very far beyond any musical requirements.

A description of the broadcasts of standard frequencies and other services made available by the Bureau is contained in Letter Circular LC565, a copy of which can be obtained

upon application to the Radio Section, National Bureau of Standards, Washington, D. C. These services include: (1) standard radio frequencies, (2) standard time intervals in the form of pulses accurately spaced one second apart, (3) standard audio frequency of 1,000 cycles per second, (4) standard musical pitch, 440 cycles per second, (5) bulletins of information on the ionosphere and radio transmission conditions.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, OCTOBER 18, 1939.

The regular monthly meeting was called to order at 8:15 o'clock by Mr. Philip C. Staples, President.

The minutes of the May meeting were approved as printed in the June issue of the Journal.

The Secretary announced that the additions to membership since the last meeting were as follows:

Honorary	1
Sustaining	7
Active	44
Associate	43
Student	140
Total	235

He also called attention to the series of lectures under the general title "Meet Doctor Franklin" on alternate Friday afternoons during the present season, the opening address by Dr. Carl Van Doren being scheduled for the twentieth instant. The entire conference has been arranged under the auspices of the Friends of Franklin by The Franklin Institute, American Philosophical Society and The Historical Society of Pennsylvania.

Brief mention was also made of the traveling shows devoted to chemistry and aviation.

There being no further business the Chairman introduced Dr. Thomas H. Johnson, Assistant Director of the Bartol Research Foundation, who spoke on "Cosmic Rays: What Has Been Learned About Them." After a brief introduction for acquainting the audience with the methods used in observing cosmic rays, the sequence of experimental results was related showing how we have come to identify the primary cosmic ray particles as electrons, both positive and negative, and protons. The methods for measuring the energies of the cosmic ray particles up to 10^{18} electron volts were described and the results stated. These rays, whose properties are well known when their energies are low, exhibit some unusual effects at high energies, and these were described. One of these effects is the production of a heretofore unknown type of ray called the meson, a particle whose mass is greater than that of the electron but less than that of the proton. Its very unusual properties were featured in the lecture. Lantern slides and many demonstrations were shown.

The meeting adjourned at 9:35 o'clock.

After adjournment Dr. Johnson continued his demonstrations and experiments.

HENRY BUTLER ALLEN,
Secretary.

LIBRARY NOTES.

The committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print $8\frac{1}{2} \times 11$ inches is forty cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 562 readers made use of the facilities during the twenty-five days of September.

RECENT ADDITIONS.

AERONAUTICS.

NEEDHAM, C. H. LATIMER. Aircraft Design. Volume 1: Aerodynamics. 1939.
TEICHMANN, FREDERICK K. Airplane Design Manual. 1939.

AGRICULTURE.

CONNORS, CHARLES H., AND VICTOR A. TIEDJENS. Chemical Gardening for the Amateur. 1939.
WRIGHT, C. HAROLD. Soil Analysis. Second Edition. 1939.

BIOGRAPHY.

DUDLEY, E. LAWRENCE. Benjamin Franklin. 1915.
FRANKLIN, BENJAMIN. Autobiography of Benjamin Franklin. Edited with an Introduction by Percy H. Boynton. 1926.

CHEMISTRY AND CHEMICAL TECHNOLOGY.

DARRAH, JUANITA E. Modern Baking Powder. 1927.
GARDNER, HENRY A. Physical and Chemical Examination of Paints, Varnishes, Lacquers and Colors. Ninth Edition. 1939.
HODGMAN, CHARLES D., Editor. Handbook of Chemistry and Physics. Twenty-third Edition. 1939.
Organic Syntheses. Volume 19. 1939.
RICHTER, VICTOR VON. Organic Chemistry. Volume 1. Third Edition. 1934.
SIMONDS, HERBERT R. Industrial Plastics. 1939.
SNELL, FOSTER DEE, AND CORNELIA T. SNELL. Chemicals of Commerce. 1939.
ZHITKOVA, A. S. Some Methods for the Detection and Estimation of Poisonous Gases and Vapors in the Air. 1936.

DICTIONARIES.

TEN BRUGGENCATE, K. Engelsch Woordenboek door A. Broers. Two volumes. 1932–1933.

ELECTRICITY AND ELECTRICAL ENGINEERING.

COURSEY, PHILIP R. Electrolytic Condensers. Second Edition. 1939.
CROFT, TERRELL. Practical Electric Illumination and Signal-Wiring Methods. Revised by George H. Hall. Third Edition. 1939.
MEYER, ERWIN. Electro-Acoustics. 1939.

SMYTHE, WILLIAM R. Static and Dynamic Electricity. First Edition. 1939.
VILBIG, FRITZ. Lehrbuch der Hochfrequenztechnik. Zweite, verbesserte u. erweiterte Auflage. 1939.

GEOLOGY AND GEOPHYSICS.

ADAMS, FRANK DAWSON. The Birth and Development of the Geological Sciences. 1938.
American Institute of Mining and Metallurgical Engineers. Transactions (Petroleum Division) Petroleum Development and Technology. 1939.
FLEMING, J. A., Editor. Terrestrial Magnetism and Electricity. First Edition. 1939. Physics of the Earth—VIII.
LEGGET, ROBERT F. Geology and Engineering. First Edition. 1939.
MATHER, KIRTLEY F., AND SHIRLEY L. MASON. A Source Book in Geology. First Edition. 1939.
ROUSH, G. A. Strategic Mineral Supplies. First Edition. 1939.

MANUFACTURES.

ROBINS, F. W. The Story of the Lamp (and of the Candle). 1939.

MATHEMATICS.

BALL, W. W. ROUSE. Mathematical Recreations and Essays. Eleventh Edition. 1939.
BIERENS DE HAAN, D. Nouvelles Tables d'Intégrales Définiès. Edition of 1867—Corrected. 1939.
BOWMAN, F. Introduction to Bessel Functions. 1938.
MCLACHLAN, N. W. Complex Variable and Operational Calculus with Technical Applications. 1939.

MECHANICAL ENGINEERING.

BATTEN, M. I. English Windmills. Volume I. 1930.
CLOWER, JAMES I. Lubricants and Lubrication. First Edition. 1939.
International Congress for Applied Mechanics. 5. Cambridge, Mass. 1938. Proceedings. 1939.

MINING AND METALLURGY.

American Institute of Mining and Metallurgical Engineers. Transactions (Institute of Metals Division). 1939.
American Institute of Mining and Metallurgical Engineers. Transactions. Milling Methods. 1939.

NAVAL ARCHITECTURE AND NAVIGATION.

ROSSELL, HENRY E., AND LAWRENCE B. CHAPMAN, Editors. Principles of Naval Architecture. Two volumes. 1939.

PHOTOGRAPHY AND PRINTING.

FINSTERWALDER, RICHARD. Photogrammetrie. 1939.
WROTH, LAWRENCE C. The Colonial Printer. 1938.

PHYSICS.

BRODE, WALLACE R. Chemical Spectroscopy. 1939.
BROGLIE, LOUIS DE. Matter and Light. 1939.

D'ABRO, A. The Decline of Mechanism (in Modern Physics). 1939.
DARROW, KARL K. Introduction to Contemporary Physics. Second Edition. 1939.
HARRISON, GEORGE RUSSELL. Atoms in Action. 1939.
KING, HORACE WILLIAMS. Manning Formula Table for the Solution of Pipe Problems. First Edition. 1937.
KING, HORACE WILLIAMS. Manning Formula Tables for Solving Hydraulic Problems. First Edition. 1939.
SMYTH, HENRY DE WOLF, AND CHARLES WILBUR UFFORD. Matter, Motion and Electricity. First Edition. 1939.
THIEL, A. Absolutkolorimetrie. 1939.
THIRRING, HANS, AND OTTO PAUL FUCHS. Photowiderstände. 1939.
WOOD, ROBERT WILLIAMS. Supersonics. 1939.

SANITARY ENGINEERING.

Federation of Sewage Works Associations. Modern Sewage Disposal. Langdon Pearse, Editor. 1938.
STEEL, ERNEST W. Water Supply and Sewerage. First Edition. 1938.

NOTES FROM THE BARTOL RESEARCH FOUNDATION.

NUCLEAR TRANSMUTATIONS OF THE LITHIUM ISOTOPES.*

BY

L. H. RUMBAUGH, R. B. ROBERTS, AND L. R. HAFSTAD.†

Yield curves have been obtained for eight of the more important reactions of Li^6 and Li^7 produced by proton and deuteron bombardment in the energy range from 200 to 1000 kev. Each curve was obtained with an accuracy of about five per cent., and a set of intercomparisons served to determine the relative yields between the different reactions within 20 per cent. A special set of observations on a single reaction then gave the absolute yield for all the reactions within a factor of about three. An investigation was made of the reactions involved in the formation and decay of Li^8, the mass of which was found to be 8.02499 ± 0.00020. The range-distribution of the delayed alpha-particles from Li^8 was measured and the interpretation of this distribution is discussed. Observations on the reaction $Li^6 + n \rightarrow He^4 + H^3$ gave a value of 4.97 Mev. for the reaction energy as compared to a value of 4.56 Mev. derived from the masses involved. No evidence could be obtained for the production of Li^8 by the process $Li^7 + n \rightarrow Li^8$. Measurements of the energies of the neutrons produced by deuteron bombardment of Li^6 indicated that Be^7 is formed by the reaction $Li^6 + D^2 \rightarrow Be^7 + n$. Further experiments showed that Be^7 is radioactive and is converted to Li^7 by K-electron capture. It was found that this process is followed by gamma-ray emission in roughly ten per cent. of the transitions.

* An abstract of a paper published in full in the *Physical Review*, **54**, 657 (1938).

† Drs. Roberts and Hafstad are members of the staff of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington D. C.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Hydrolysis of Glutathione by Blood Serum.—GLADYS ESTELLE WOODWARD. (*Biochemical Journal*, 33: 1171, 1939.) A significant alteration in the blood of cancerous individuals as distinguished from those who are cancer-free has long been sought. A difference, if present, would lead to the early diagnosis of cancer and thereby permit early treatment which is essential for a cure.

Recently Waldschmidt-Leitz reported that the serum of cancer blood differed from normal serum in that it produced hydrolysis of the glutathione molecule while normal blood caused no such hydrolysis. Very few cases were studied. Confirmation of this report on a larger number of cases seemed highly desirable. His observation was based upon the increase in free amino-groups in mixtures of oxidized glutathione and serum after incubation. The cleavage of glutathione was assumed to be brought about by antiglyoxalase.

Antiglyoxalase, an enzyme (or enzyme system) which destroys the ability of reduced glutathione to activate glyoxalase, had been studied extensively in this laboratory. It had been found only in kidney and pancreas extracts, kidney containing by far the larger amount. In our former work, two very specific tests had been employed to measure the cleavage of glutathione: (1) loss of glyoxalase activating power; (2) formation of cysteine.

In the present study, these two tests have been applied to mixtures of oxidized glutathione and serum after incubation for 24 hours. At the end of this time the mixture was deproteinized with sulfosalicylic acid, the filtrate reduced by the electrolytic reduction procedure recently developed in this laboratory by Dohan and Woodward, and the reduced filtrate analyzed for the glutathione still remaining and the cysteine formed. With all sera, whether cancerous or otherwise, varying amounts of glutathione cleavage were found. With 10 normal sera the cleavage was from 16 to 99 per cent.; with

10 cancer sera, 11 to 81 per cent.; and with sera from 10 individuals with other pathological conditions, 11 to 72 per cent. Cysteine formation was of the same order. The degree of hydrolytic activity of serum, therefore, cannot be used as a diagnostic test for cancer, since there was no significant difference between the action of the normal and the cancer or other pathological sera examined.

A Simplified Isolation of Glutathione from Yeast.—ELMER FREDERICK SCHROEDER, VINES COLLIER, JR., AND GLADYS ESTELLE WOODWARD. (*Biochemical Journal*, **33**: 1180, 1939.) Several different methods have been used for isolating glutathione in pure form from natural sources. This interesting sulfur compound, composed of the amino acids glycine, cysteine, and glutamic acid, occurs in practically all types of tissues. Although it has been separated in crystalline form from liver, red blood cells, and other tissues, for practical purposes it is at present obtained exclusively from yeast.

The original method of isolation (Hopkins, 1921) was exceedingly complicated and time-consuming, and moreover led to an amorphous product. In 1929 Hopkins was able to obtain crystalline glutathione from yeast by a much simpler method. He found that glutathione reacted with cuprous oxide to form a characteristic, highly insoluble copper compound, which could be separated out and then converted into free glutathione. This method was still tedious because, before the copper salt could be obtained, it was necessary to isolate the glutathione as its mercury salt. In the following year Pirie found a way in which the mercury salt step could be avoided. Yeast was plasmolyzed by means of a sulfuric acid-alcohol-ether mixture. The extract obtained by filtering off the yeast residue from such a mixture contained much of the glutathione, which could then be isolated by means of the cuprous salt. This method, although a considerable improvement, suffers from the fact that the removal of the yeast residues by filtration is an exceedingly slow process, requiring 6 or more hours even *in vacuo*.

A procedure has now been developed whereby this long filtration period can be reduced to about 20 minutes. Yeast is stirred up with acetone for a few minutes, in order to liber-

ate the glutathione from the cells. After removal of the acetone, the glutathione is extracted from the residual yeast by a few minutes' stirring with water. A large quantity of infusorial earth is added, and the mixture filtered rapidly with suction. When the clear yellowish filtrate thus obtained is acidified and treated with cuprous oxide, a heavy white precipitate of cuprous-glutathione is formed. The latter is thoroughly washed, the copper removed with hydrogen sulfide, and the glutathione brought to crystallization in a vacuum desiccator.

Starting with the original yeast, it is possible by the new method to complete the precipitation of the cuprous glutathione within one hour. Crystalline glutathione may be obtained in less than two days. A minimum of apparatus and labor is required. The crude crystals obtained in the first crystallization are about 98 per cent. pure. After one recrystallization, the sulfur content was 10.43 per cent., as compared to a theoretical of 10.42 per cent.

An average sample of fresh pressed baker's yeast contains about 1.5 grams of glutathione per kilogram of yeast (wet weight). Of this, about 50 per cent. can be isolated in crystalline form by the method just outlined. By working up residues and mother liquors more carefully this yield could be increased. But in view of the low cost of yeast such a procedure is not worth while when only small quantities of product are needed.

Scientific Visit to Svedberg's Laboratory of Dr. E. B. Sanigar of the Biochemical Research Foundation's Staff.—As the Biochemical Research Foundation has gone quite extensively into the investigation of ultra-centrifuges and centrifugation for the fractionation and identification of biological substances such as hormones, organ extracts, cancer sera, etc., it was thought wise by the Director to have Dr. Sanigar of the Staff visit Professor The Svedberg, Director of the Physico-Chemical Institute of the University of Upsala. Accordingly permission was sought from, and graciously given by Dr. Svedberg who is not only a Nobel prize winner but is also a Medallist of The Franklin Institute.

It was felt in July that as war seemed imminent there might for some years be no opportunity for visits to and fro and that Dr. Svedberg, who often has been in our laboratories, might not soon have the opportunity of visiting us again.

Dr. Sanigar therefore was sent to Upsala on the indicated scientific mission and has brought back many important details and much valuable information which would be difficult for us to obtain otherwise. Below are excerpts from his report of his visit.

"The main objects of the visit to Dr. Svedberg's Laboratory can be roughly divided into three groups: to study (a) their methods of running centrifuges, (b) their different methods of calculation of sedimentation and diffusion results, and (c) new developments and techniques. Many of the recent alterations in technique, e.g., the use of full oil pressure for the acceleration of the rotor to the desired speed, followed by decrease of the oil pressure to the value required to maintain the rotor at desired speed, and the use of magnetic brakes for stopping the rotor, cannot be applied to the Wilmington centrifuge because of the size of journals (18 mm. journals, single turbines as against improved 10 mm. journals, twin turbines now used in Upsala).

"One of the latest changes in Upsala is the mounting of two centrifuges on the same concrete foundation. The cameras are side by side, as are the other pieces of auxiliary apparatus and the control panels, giving a compact assembly and enabling one technician to supervise both centrifuges simultaneously. The newer of these two centrifuges has a much smaller driving unit than has been customary hitherto, the centrifugal pump of special design capable of operating in a vacuum having been replaced by a much smaller de Laval screw pump (Imo) provided with a vacuum shield. This has resulted in an increased over-all efficiency and a reduction in the cost of running, the power consumption for oil-drive now being somewhat lower than for the usual type of air-drive.

"It is of interest that, when balancing a rotor, instead of rotating it always in the same direction, the method now employed in Upsala is to rotate the rotor both clockwise and counter-clockwise for each setting of the balancing cell. Thus two curves having minima are obtained, and the balance

setting is taken as the midpoint between these minima. The use of balancing-cell settings determined in this manner is stated to result in less vibration during the starting and stopping, as well as during the running, of the centrifuges. An improved type of balancing cell is now in use at Upsala, the function of the cell being the same but the variation in its effectiveness as a balancing agent being obtained by the screwing in of plugs of different weights and the adjusting of the position of the inserted plug. There has also been an alteration made in the shape of the hole in the balancing cell through which the light passes in order to give the reference block on the photographic plate.

"Dr. Svedberg and those of his staff concerned were very kind in permitting drawings of new apparatus to be made. Tracings were made from the original drawings for (1) the new pusher for inserting and ejecting cells from the rotor, (2) the latest type of scale projection outfit, (3) Svensson's wedge-shaped slit of variable angle devised for obtaining clearly defined, direct photographs of electrophoresis diagrams utilizing the Schlieren method, and (4) a new type of comparator.

"One of the operators in the calculating room coöperated by reading a number of scale photographs taken in Wilmington; carrying through the complete calculations while the entire procedure was observed. The results obtained showed perfect agreement with those already calculated here. The method of handling plate reading and calculations in Upsala is worthy of note. Two technicians spend practically their entire time reading plates by means of the various comparators, only occasionally drawing the resulting curves. Another member of the calculating staff usually constructs the curves and makes the final calculations. The use of the latest type of calculating machines and the fact that the various operators are experts in their particular operations enable the workers to calculate results of centrifuge runs with surprising speed.

"As our work in the near future will probably necessitate the measurement of diffusion coefficients, the opportunity was taken of discussing with different members of the staff at Upsala the various methods of calculating these coefficients. Five methods, the broad outlines for some of which have

already been published, were discussed in detail. Various diffusion cells were examined including the standard Lamm metal diffusion cell and three glass cells for use particularly with non-aqueous solvents. The most recent developments in electrophoresis technique and apparatus were also discussed.

"One of the most interesting things examined during the visit to Upsala was a proof copy of the manual on centrifuges and centrifugation, 'The Ultracentrifuge,' which has been written by Professor Svedberg and Dr. Pedersen, with several collaborators. Of particular interest among the many valuable items in the manual was some hitherto unpublished work done in Upsala on serum proteins, and on the effect of different serum diluents on the shape of the sedimentation curves obtained from the same human serum. As has already been briefly noted in publications (although the details of recent work have not yet been published), the use of phosphate buffer in place of sodium chloride solution as diluent for human serum may cause the *X* constituent (probable molecular weight about 80,000) shown on the serum diagram to disappear entirely. This disappearance is accompanied by the formation of a new *Y* component, or of components Y_1 and Y_2 (of probable molecular weight 40,000 and 20,000 respectively and having sedimentation constants differing from that of the original *X* component), in an amount exactly equal to the original quantity of *X* substance. As with the *X* substance, the *Y* substance disappears on further dilution, an equal quantity of normal globulin appearing in place of either.

"Centrifugal analysis for the protein fractions of serum was discussed in detail, particularly new and as yet unpublished work, because it is hoped to continue our work on the comparison of cancer serum and normal human serum by means of the ultracentrifuge. Our work on pathological sera need not, however, be limited to cancer sera since this extensive field (of the investigation of pathological sera by means of the ultracentrifuge), first investigated by McFarlane in 1935, is not, as far as could be learned, being widely studied. A scale projection outfit is necessary for the examination of such sera because it has been definitely established that sera diluted to the point where a scale distance of 3 cm. can be used (the minimum obtainable distance without a projection apparatus)

give sedimentation diagrams differing from those obtained with the undiluted sera because of the protein changes brought about by dilution.

"It is a pleasure to place on record here appreciation of the kindness and courtesy shown by everyone during the visit to Upsala, and also to express appreciation of having had the opportunity of furthering the close contact which exists between the Physico-Chemical Institute of the University of Upsala and the Biochemical Research Foundation of The Franklin Institute."

BOOK REVIEWS.

INDUSTRIAL SOLVENTS, by Ibert Mellan. 480 pages, illustrations, tables, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1939. Price $11.00.

This book attempts to cover the complete data of solvent technology in a single volume of 480 pages. It is largely tabular and graphical in form. The reviewer estimates that graphs and tables occupy at least half the book.

The first seven chapters cover discussions and theories of general applicability, and include the following subjects:

I. Solution, Theories and Aggregates;
II. Solvents, Latent Solvents, Non-Solvents;
III. Plasticity;
IV. Vapor Pressure, Evaporation Rate, Boiling Point;
V. Viscosity;
VI. Volatility, Inflammability, Toxicity;
VII. Solvents and Their Use in the Industries.

Chapters VIII to XVI give the above data as applied to the various classes of organic compounds: hydrocarbons, halogenated hydrocarbons, alcohols, aldehydes, acids, ketones, ethers and esters. Chapter XVI discusses plasticizers and chapter XVII is an interesting treatment on graphical expression of results.

The tabular nature of presentation of the data makes the book particularly applicable to laboratory work.

A great deal of the subject matter has been taken bodily from published works, however, this does not detract from the usefulness of the book, and the author has been careful to cite references in each case.

There has been a tendency to scatter data throughout the book—for example, data on vapor pressures are found in chapter IV and also under individual compound headings. The information on toxicity given in chapter VI is extremely brief. It would seem that this chapter could have been enriched by reference to the excellent work of Ethel Browning on the subject.

However, in the opinion of the reviewer, the failings of the book are few, and, as a reference book on organic solvents, it must be looked upon as one of the best available.

G. S. GARDNER

EXPLOSIONS- UND VERBRENNUNGSVORGÄNGE IN GASEN, von Dr. sc. nat. Wilhelm Jost. 608 pages, illustrations, tables, 17 × 25 cms. Berlin, Julius Springer, 1939. Price 49.50 R.M.

This book, as the title implies, has for its purpose the presentation of experimental and theoretical facts regarding the process of explosion and combustion of gases. From the coverage of this, practical utilization may be had and in addition

further research may be carried on. There has been a large gap in publications in book form on this subject, data being limited to a very few books over a long period of years. Reports of work were mostly confined to society proceedings and articles in technical periodicals usually spread over a wide and diversified field. Recently a book on this subject has appeared in English by Lewis and von Elbe and was reviewed in these columns. The book at hand covers a similar field in German.

The subject matter is the result of an exhaustive literature search through periodicals, coupled with expert knowledge so that the presentation runs smooth and logical. The introduction deals with the question of self ignition through the application of heat from which the process of spark ignition is taken up. Flame propagation is discussed as is explosions in closed chambers, detonation, flame temperatures, the kinetics of the process of combustion and explosion, and the combustion of explosive gases and carbon monoxide. Following this, spark ignition is again taken up with respect to electrical discharge reactions, and the treatment proceeds through combustion of hydrocarbon gases, in the Otto engine, and in the Diesel engine.

The treatment is of high quality supported by unusually good illustrations, photographs and drawings of flame characteristics and explosion phenomena. There is a subject and author index in the back of the book as well as the recording of reference data throughout the text. The book is a complete compilation of thought in this field, of the work of many investigators together with the contributions of the author who is an authority.

R. H. OPPERMANN.

THE WAR GASES, CHEMISTRY AND ANALYSIS, by Dr. Mario Sartori. 360 pages, illustrations, tables, 16 × 24 cms. New York, D. Van Nostrand Company, Inc., 1939. Price $7.50.

Since the World War of 1914–18 much publicity has been given to the chemical warfare branch of military service, especially the very important subject of war gases. In back of this, considerable work has been done in various countries which is evidenced by the appearances of treatises in different languages. The study is now one of the most complicated branches of chemistry, characterized by experimental difficulty and by the necessity of coördinating chemical facts with physiopathological data and techno-military requirements.

The book at hand is the second edition originally written in the Italian language and translated into English. It is essentially a compilation of authoritative and recent published work on purely chemical data appearing in various manuals on chemical warfare. The translation is excellently done so that little or no difficulty will be experienced in following the text. Starting out with a discussion on the principal properties of war gases which are divided into the physiopathological, physical and chemical properties, the relation between chemical structure and aggressive action is then taken up. Here is an attempt in compiling the important theories and facts which show some of the relations of the toxic and irritant action of war gases on the human body in relation to the chemical structure of the molecule. Following this and without entering into unnecessary detail, a few of the more important classifications of war gases are presented with special emphasis on the chemical nature of the gases.

Part two of the book covers the various gases individually. The halogens, aromatic esters, cyanogen compounds, sulphur compounds, arsenic compounds and others are discussed giving the physical and chemical properties, detection and preparation.

The text flows smoothly and logically and is in every sense a modern version of the subject. No information is given with regard to peace time chemical application, the coverage being entirely for the war gas chemist. The author and subject index adds much to the value of the book as a work for reference.

R. H. OPPERMANN.

FERROMAGNETISMUS, von Dr. R. Becker und Dr. Ing. habil. W. Döring. 440 pages, illustrations, tables, 18 × 26 cms. Berlin, Julius Springer, 1939. Price 42.60 R.M.

The authors of this book, both of the University of Göttingen, are quite well known in this field of endeavor for their work and contributions to the literature. The book here presented is of the type representative of such men and it reflects in addition a keen insight to successful angles of approach as well as the necessary related matter for complete coverage. Generally the treatment is based first on an explanation of the phenomena and then the outward appearance or external effectiveness of the phenomena. Written in German, it is an unusually complete treatment.

The first two chapters give as an introduction the general theory of ferromagnetism rather briefly. It contains matter usually covered but in addition a new point of view is given regarding the paramagnetism with respect to Curie points. There is also a brief quantum mechanics treatment of ferromagnetism. The number of topics covered to the place where enough knowledge may be retained to use in the solution of difficult problems, is considerable. The work is brief in that of necessity the space devoted to each topic must necessarily be smaller than what would be required for a more detailed coverage of each.

What constitutes the greater part of the book are chapters three, four and five. They treat on all of the many questions relating to the magnetization curve and the attendant phenomena. The points of view which result from an interpretation of these phenomena are summarized. The character of presentation and the sequence of topics are of special merit and there are some newly worked out data presented, much of which come from experiments not yet verified a sufficient number of times but that are nevertheless indicative. The entire construction of the work seems to have an aim to give a candid view of the authors insofar as they have progressed.

The last chapter gives a survey of the different magnetic materials and the methods of their manufacture without any claim to completeness. An attempt is made to show theoretically the variations in the properties of the materials. There is finally a combined subject and author index. For those who are interested in the subject and can read German this book has value.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

United States Department of the Interior. Minerals Yearbook, 1939, compiled under the supervision of H. Herbert Hughes. 1437 pages, 15 × 24 cms. Washington, Superintendent of Documents, 1939. Price $2.00.

Blätter für Technikgeschichte, Sechstes Heft, Schriftleitung: Dr. Ing. L. Erhard. 82 pages, illustrations, 18 × 25 cms. Berlin, Julius Springer, 1939. Price 4 R.M.

Kurzes Lehrbuch der Physikalischen Chemie, von Prof. Dr. Karl Jellinek. Heft II, 292 pages, illustrations, 16 × 25 cms. Deventer, Æ. E. Kluwer Ltd., 1939. Price 7.50 h.fl.

The Glass Giant of Palomar, by David O. Woodbury. 368 pages, plates, illustrations, 16 × 25 cms. New York, Dodd, Mead & Company, 1939. Price $5.00.

United States Department of Agriculture, Weather Bureau. Daily River Stages at River Gage Stations on the Principal Rivers of the United States, compiled by Merrill Bernard, Volume XXXV, 1937. 168 pages, 23 × 29 cms. Washington, Superintendent of Documents, 1939. Price 30 cents.

Canada—Department of Trade and Commerce, Dominion Bureau of Statistics, Mining, Metallurgical and Chemical Branch. Manufactures of the Non-Metallic Minerals in Canada, 1936 and 1937. 166 pages, 17 × 25 cms. Ottawa, King's Printer, 1939. Price 25 cents.

Canada, Department of Mines and Resources, Mines and Geology Branch, Bureau of Mines. Investigations in Ore Dressing and Metallurgy (Testing and Research Laboratories), January to June, 1938. 147 pages, plates, illustrations, 16 × 25 cms. Ottawa, King's Printer, 1939. Price 50 cents.

National Advisory Committee for Aeronautics. Technical Notes: No. 726, Combined Beam-Column Stresses of Aluminum-Alloy Channel Sections, by R. Gottlieb, T. M. Thompson, and E. C. Witt. 17 pages, illustrations. No. 727, A Flight Investigation of the Distribution of Ice-Inhibiting Fluids on a Propeller Blade, by Lewis A. Rodert. 12 pages, illustrations. No. 728, Wind-Tunnel Investigation of an N.A.C.A. 23021 Airfoil with Two Arrangements of a 40-Percent-Chord Slotted Flap, by Frank Duschik. 22 pages, illustrations. No. 729, An Instrument for Estimating Tautness of Doped Fabrics on Aircraft, by Gordon M. Kline and Herbert F. Schiefer. 11 pages, illustrations. No. 730, Wind-Tunnel Investigation of Effect of Yaw on Lateral-Stability Characteristics, II—Rectangular N.A.C.A. 23012 Wing with a Circular Fuselage and a Fin, by M. J. Bamber and R. O. House. 20 pages, illustrations. 5 pamphlets, 20 × 26 cms. Washington, Committee, 1939.

Bell Telephone System, Monographs: B-1152, High Definition Television, by Pierre Mertz. 9 pages. B-1153, Improved Microtome Technique for Soft Metals, by Earle E. Schumacher and G. M. Bouton. 7 pages, illustrations. B-1154, Dielectric Measurements in the Study of Dispersions in Rubber, by A. R. Kemp and D. B. Herrmann. 15 pages, illustrations. B-1155, Application of Negative Feedback to Frequency-Modulation Systems, by J. G. Chaffee. 38 pages, illustrations. B-1156, Frequency-Modulation: Theory of the Feedback Receiving Circuit, by John R. Carson. 9 pages, illustrations. B-1157, Survey of

Magnetic Materials and Applications in the Telephone System, by V. E. Legg. 27 pages, illustrations. B-1158, The Dielectric Properties of Insulating Materials —III, by E. J. Murphy and S. O. Morgan. 36 pages, illustrations. B-1159, Impedance Properties of Electron Streams, by Liss C. Peterson. 17 pages, illustrations. B-1160, Plastic Materials in Telephone Use, by J. R. Townsend and W. J. Clarke. 20 pages, illustrations. B-1161, Room Noise at Telephone Locations, by D. F. Seacord. 7 pages, illustrations. B-1162, The Self-Diffusion of Copper, by J. Steigman, W. Shockley and F. C. Nix. 21 pages, illustrations. B-1163, Simultaneous Ionosphere Observations, by J. P. Schafer and W. M. Goodall. 4 pages, illustrations. B-1164, Fractional-Frequency Generators Utilizing Regenerative Modulation, by R. L. Miller. 31 pages; illustrations. B-1165, Cellulose as an Insulating Material, by G. T. Kohman. 26 pages, illustrations. B-1167, Inductive Coördination with Series Sodium Highway Lighting Circuits, by H. E. Kent and P. W. Blye. 17 pages, illustrations. B-1168, Electron Diffraction Studies of Thin Films—I, by L. H. Germer. 33 pages, illustrations. B-1169, The Automatic Synthesis of Speech, by Homer Dudley. 6 pages, illustrations. 17 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1939.

CURRENT TOPICS.

Liquid Coal.—Exhibiting the startling possibilities of their newest development, "Liquid Coal," scientists of the Research Foundation of Armour Institute of Technology recently showed how it was possible to operate and drive a 1939 stock model automobile (Pontiac—8 cylinder sedan) on coal. This newest development in research goes to the credit of DR. F. W. GODWIN, Director of the Coal Research Division of the Research Foundation. The demonstration was witnessed by a delegation of pressmen, scientists, and coal dealers and producers attending the American Retail Coal Convention and Exposition. The test with coal was made on the standard car engine without any changes of any kind in carburetion or in the ignition system of the motor, with the exception of the removal of one fine-screen filter. According to Dr. Godwin, three different types of colloidal fuel have been used successfully in the tests on the stock model to date. The first of these fuels was a suspension of a specially prepared coal, ground to 300 mesh in a mixture of gasoline, fuel oil, and lubricating oil. The second test with the liquid coal was made with a suspension of coal in a diesel oil. The third test was made with a suspension of the coal in a very light oil. The test and demonstration was carried out with a more elaborate preparation of the fuel. A very light oil, or a form of range oil with a light fraction of hydrocarbon was used as the vehicle, followed by special treatment with the coal, resulting in the suspension of coal of about 500 mesh. In each case, before the liquid coal was introduced into the auxiliary fuel tank on the automobile, it was chemically stabilized in order to hold the coal in suspension. Although liquid coal is not a product that is ready for the market or, more specifically, ready for consumer use in automobiles, the possibilities as shown in the demonstration are tremendous. Especially is this fuel desirable for the home owner who has been concerned with the problem of heating. It was pointed out that this fuel has been used in many types of domestic and commercial oil burners during its development, and that the heat value per cubic foot as proved by these tests is considerably more than either coal or oil alone.

R. H. O.